Utilisation of Poplar Lane Quarry (PLQ) basecourse aggregate as a suitable source for roading material

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Abstract

The scope of this research was to assess the utilisation of Poplar Lane Quarry (PLQ) basecourse aggregate as a suitable source for roading material. Poplar Lane Quarry (PLQ) basecourse aggregate generally, but not consistently, meets the current M/4 specifications, and the effect of proposed revisions to M/4 on consistently satisfying required properties of M/4 is unknown.

In the past there have been some premature pavement failures when using PLQ aggregate which were at times unexplained as the aggregate met and exceeded the TNZ M/4 specification. Smectite clays were known to be present in the rock and may have been an influencing factor into the aggregate breakdown.

The objective of this research was to thoroughly investigate the properties and production processes of PLQ basecourse material in relation to the TNZ/NZTA specifications and relevant tests, in an effort to improve the correlation between the tests and the actual performance of the material. This included analysing historic M/4 test results as well as collecting material to conduct a full range of M/4 test. Additional analysis included the NZTA T20 Accelerated Weathering test, stabilising and strength testing, mineralogy analysis and failure plane analysis.

The results of the M/4 speciation testing and review indicated that the Plasticity Index and Clay index showed variable results over the years and at times did not meet the specification. The Clay Index values are accepted in the industry as identifying the presence of expansive clays where in fact this is not the case. Further clay analysis was conducted and it was found that no expansive clays such as smectite were present, instead the non-expansive clay halloysite was found. The variability in the Plasticity Index can be attributed to a number of factors, one being the variability of clays within the quarry and the competency of the laboratory technicians.

Following these initial tests and analysis further investigation were conducted. The NZTA T20 Accelerated Weathering test, which was not yet finalised for all regions when this thesis was

completed, was found to provide inconclusive results. The PLQ aggregate and greywacke control stone failed to meet the proposed limit; these findings were passed onto the external authors of the test method for consideration. SEM analysis was conducted on the samples to aid in the identification of the clay type and content, this was inconclusive as no clays could be identified, but extensive alteration was found throughout. The expected failure planes of the aggregate was investigated using quarry wall mapping, hand sample analysis, thin section analysis and SEM. Joints and faults were found on the macro scale and micro-veins that pinched and swelled were found in the hand sections. Fracturing was observed in and around many minerals.

In conclusion, the PLQ aggregate continues to meet the requirements of the TNZ M/4 and draft NZTA M/4 Specification. The Clay Index test does not give an accurate identification of deleterious clays and may not be fit for purpose. The Plasticity Index has variable results related to either the clay type and content of the aggregate or the competency of the technicians. The clay found within the aggregate was halloysite which is non-expansive and will not cause aggregate breakdown from swelling. The NZTA Ethylene Glycol Accelerated Weathering test needs further review and testing to determine the appropriate limits. Failure planes, such as joints and micro-veins within the rock may decrease the structural integrity of the aggregate, but this can be combated by stabilising with 1% cement.

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1. Chapter One: Introduction

1.1 Background

Poplar Lane Quarry (PLQ) is owned by Fulton Hogan and is located in the Bay of Plenty, New Zealand (Figure 1.1 and 1.2). The quarry is situated in the Otawa Formation, which is comprised of dark grey, fine- to medium-grained porphyritic andesite lavas containing phenocrysts of plagioclase, hypersthene, hornblende, augite and minor quartz (Briggs, et al., 1996). In 1998, Fulton Hogan purchased the Maketu quarry and renamed it Poplar Lane Quarry; one of the quarry's products is basecourse aggregate used in the construction of roads in the region.

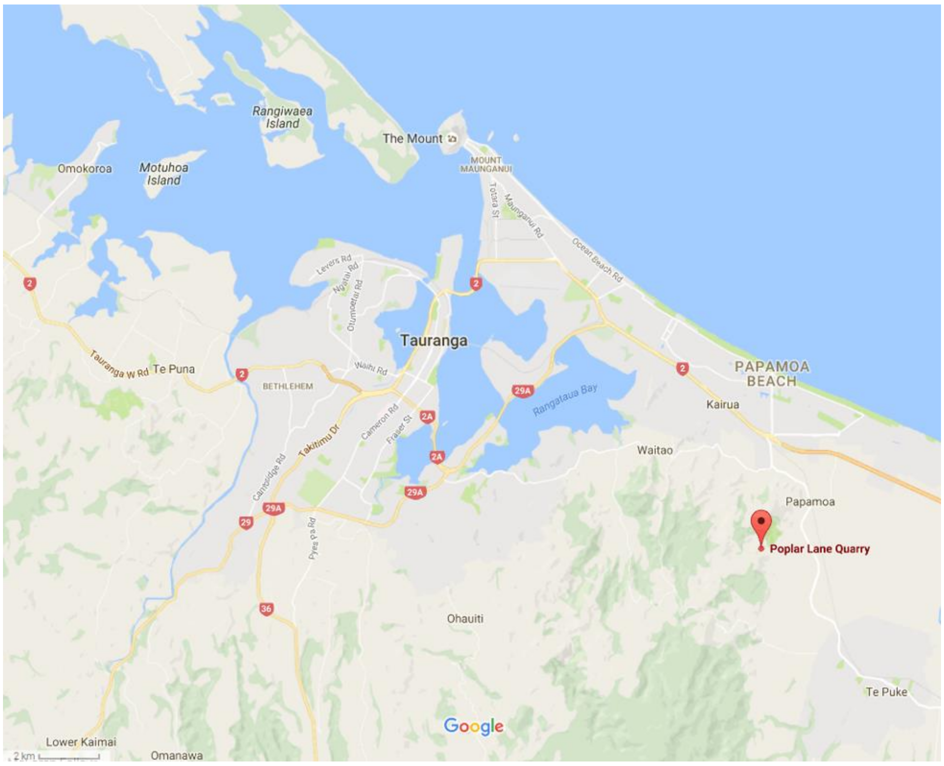

Figure 1.1 Tauranga Region. Poplar Lane Quarry identified by the red marker pin. Extracted from Google.com (20/11/2016)

Figure 1.2 Poplar Lane Quarry. Extracted from google on the 20/11/2016

In the past, some roads constructed using PLQ aggregate have experienced premature rutting, due to a variety of causes. This was unexpected as the aggregate had met or exceeded the source property standards set by the New Zealand Transport Agency (NZTA).

All basecourse aggregates that were produced by PLQ and used in road construction complied with the TNZ M/4 (TNZ, 2006), undergoing and passing the numerous laboratory tests (refer to TNZ M/4 for full list of tests (TNZ, 2006)) from source to production. One of the issues at PLQ requiring special attention is dealing with a quantity of overburden containing highly plastic smectite (swelling clays) fines (Bartley, et al., 2007). Smectite clays are known to cause performance problems with roading aggregates as they swell when in contact with water causing the breakdown of the rock.

Compliance with the TNZ M/4 (2006) specifications should have ensured that PLQ aggregate would perform adequately under traffic loading. The NZTA is drafting a new basecourse material standard, which is yet to be released, specifying tighter parameters including additional testing. In order for PLQ material to meet these standards it is important to revisit the PLQ basecourse properties and test results to identify areas for possible improvement. With some material additional testing (not included in the TNZ M/4 standards) and subsequent material improvement may be required to ensure all properties are elucidated and all specifications are met. For instance, the additional test included in the Quality of Fines (NZTA, 2012) (yet to be investigated) criterion highlights an area of concern for the PLQ aggregate which despite meeting the specification, has at times displayed inconsistent performance relating to fines.

1.2 Scope

The scope of this research was to assess the utilisation of Poplar Lane Quarry (PLQ) basecourse aggregate as a suitable source for roading material. Poplar Lane Quarry (PLQ) basecourse aggregate generally, but not consistently, meets the current M/4 specifications, and the effect of proposed revisions to M/4 on consistently satisfying required properties of M/4 is unknown.

Investigating and analysing PLQ aggregate quality and production processes determines the most suitable application for the material as a basecourse. A new testing regime may be required for the PLQ aggregate to ensure new material specifications are met.

The limitations surrounding this research included;

- Poplar Lane Quarry TNZ AP40 was the subject of this investigation, with only one other quarry material used as a control stone
- TNZ M/4 2006 Specification for basecourse aggregate governed the testing requirements
- NZS 4407:1991 Methods of sampling and testing road aggregates govern the collection of samples and test methods
- The control stone was sourced from Canterbury's Miners Rd Quarry

1.3 Thesis Objectives

The objective of this research has been to thoroughly investigate the properties and production processes of PLQ basecourse material in relation to the TNZ/NZTA specifications and relevant tests, in an effort to improve the correlation between the tests and the actual performance of the material. To this end, the following research has been conducted:

1. Collate and review historical PLQ aggregate test reports and correlate/compare these with the TNZ M/4 specification.
2. Assess the aggregate production processes to determine if these have an effect on the performance of the material.
3. Obtain a full range of material properties by conducting laboratory tests on samples of PLQ aggregate at varying grades of weathering, from slightly weathered to completely weathered aggregate.
4. Investigate the geology of PLQ and determine and confirm its mineralogy and any susceptibility to alteration, including formation of deleterious minerals in certain layers.
5. Analyse mineral alteration and variability both laterally and vertically within the PLQ, using thin section petrography and XRD analysis, and to identify poor aggregate performance.
6. Investigate the smectite distribution in, and the influence of smectite clays on the PLQ aggregate.
7. Analyse the fracturing characteristics of the PLQ aggregate and its influence on the performance of the aggregate.
8. Perform additional tests on the PLQ aggregate to further determine the suitability of the material as a basecourse aggregate.

1.4 Thesis Methodology

The purpose of this introduction has been to demonstrate the relevance and important of this research to the utilisation of Poplar Lane Quarry and subsequent roading industry in New Zealand.

The research investigated a number of avenues that highlight the properties of the PLQ aggregate and detail how the draft specification affects the basecourse material from a quarry.

Material was collected from PLQ and scrutinised under a number of tests, including those required for the TNZ M/4 speciation as well as numerous other tests to further determine the materials properties.

The three main focus areas included;

- Investigating the current and proposed specification and detail how PLQ basecourse performs against the requirements.
- Investigating and analysing PLQ aggregate quality and production processes will determine the most suitable application for the material as a basecourse.
- Determining a new testing regime to ensure new material specifications are met

The preferred benefit will to find an economically viable application to ensure the PLQ basecourse it utilised in the most effective conditions.

1.5 Thesis Organisation

Chapter Two: Literature Review

Previous investigations and studies conducted on Poplar Lane Quarry as well as topics which are relevant to the research are reviewed in this chapter. This chapter also summaries the current NZTA M/4 basecourse standard and the proposed draft M/4 standard, highlighting the differences between the two, and how the draft standard will affect the PLQ aggregate and its associated limitations.

Chapter Three: Field Investigation

This section outlines and details field work relevant to this research, describes the sampling process and material selection, and reviews the processing and crushing procedures. There are also geological maps, aerial photographs and historical maps and data,

Chapter Four: Laboratory Data

A summary of all basecourse TNZ M/4 historic test reports from PLQ is summarised. Data obtained from tests performed according to the current TNZ M/4 standard, the proposed standard, including thin sections, x-ray diffraction (XRD) analysis and other tests are included in this chapter.

Chapter Five: Analysis and Discussion

An in-depth discussion and analysis of the data and results, which have been illustrated, tabulated and graphed where possible, presented in this chapter.

Chapter Six: Summary and Conclusions

This chapter details the primary results and conclusions and summaries the thesis objectives. Recommendations for future work have been outlined.

2. Chapter Two: Literature Review and Testing Methodology

2.1 Introduction

This literature review was conducted to investigate previous research surrounding Poplar Lane Quarry (PLQ) aggregate, and a range of factors that affect pavement performance. It details the following;

- Geology of the Region
- Geology of the Study Area
- New Zealand Road Design
- Basecourse Failure Mechanisms
- Factors Effecting Permanent and Resilient Deformation
- Basecourse Degradation
- Crushing Aggregates
- Clays in Aggregates
- Additional testing
- Stabilising Basecourse
- Review of the current and draft M/4 specification

2.2 Geology of the area

The PLQ quarry is located in the Papamoa range in the Tauranga region and is developed in late Pliocene Otawa volcanics and includes a sequence of NNE dacite and rhylotic domes (Briggs et al, 1996). The Matua Subgroup of terrestrial and submarine deposits interlayer with these volcanics.

The main physiographic units making up the Tauranga basin include; Kaimai Range, Whakamarama Plateau, Tauranga Basin, Marnaku Plateau, Papamoa Range and a group of volcanic domes (Figure 1). A complete geology of the Tauranga area can be found in Appendix A.

2.2.1 Regional Setting

The Tauranga region is bounded by the Kaimai ranges to the North and North West (Figure 2.1). Movement on the Hauraki Fault, which bounds the range on the West, caused the uplift of the Kaimai range. The Kaimai range comprises Miocene- Pliocene basaltic to rhyolitic volcanic rocks (Briggs et al., 1996).

The Whakamarma Plateau forms the base of the western portion, stretching from the Kaimai ranges to the Tauranga Basin. It dips in a north easterly direction at 3-5°. The plateau forms the basement below the Tauranga basin at depths between 50 and 150 m (Briggs et al, 1996).

The Tauranga Basin (570 km^2) is a Pleistocene, fluvial/estuarine basin. During a period of rapid subsidence the basin was partially infilled with volcaniclastic terrestrial and estuarine sediments as well as welded and non-welded ignimbrites (Briggs et al., 1996). Tauranga Harbour is a mesitidal estuarine lagoon of 200 km^2 and occupies most of the basin. The main river entering the basin is the Wairoa River, which flows between the Whakamarama Plateau and Mamaku Plateau (Figure 2.1) (Briggs et al., 1996).

The Mamakau Plateau located to the south of the basin slopes at an angle of 1-2°. The plateau is a depositional feature comprising pyroclastic flows formed in thick fans and lobes, and is underlain by the Mamakau ignimbrites which thins toward the Tauranga Basin (Briggs et al., 1996).

The Papamoa range is bounded to the south by the Mamaku Plateau and is located between the Tauranga and Maketu basins. It comprises Pliocene andesitic volcanics, a series of Pleistocene dacite and rhyolitic domes and dacitic ignimbrites. The alignment of the volcanic domes is thought, by Briggs et al. (1996) to be controlled by two NNE striking faults that border the range on either side, as mapped by Healy & Thompson (1964). The volcanic domes which are prominent features within the Tauranga region are mostly ryholitic domes with some dacitic domes. There are five rhyolitic and one dactic domes in the Papamoa region.

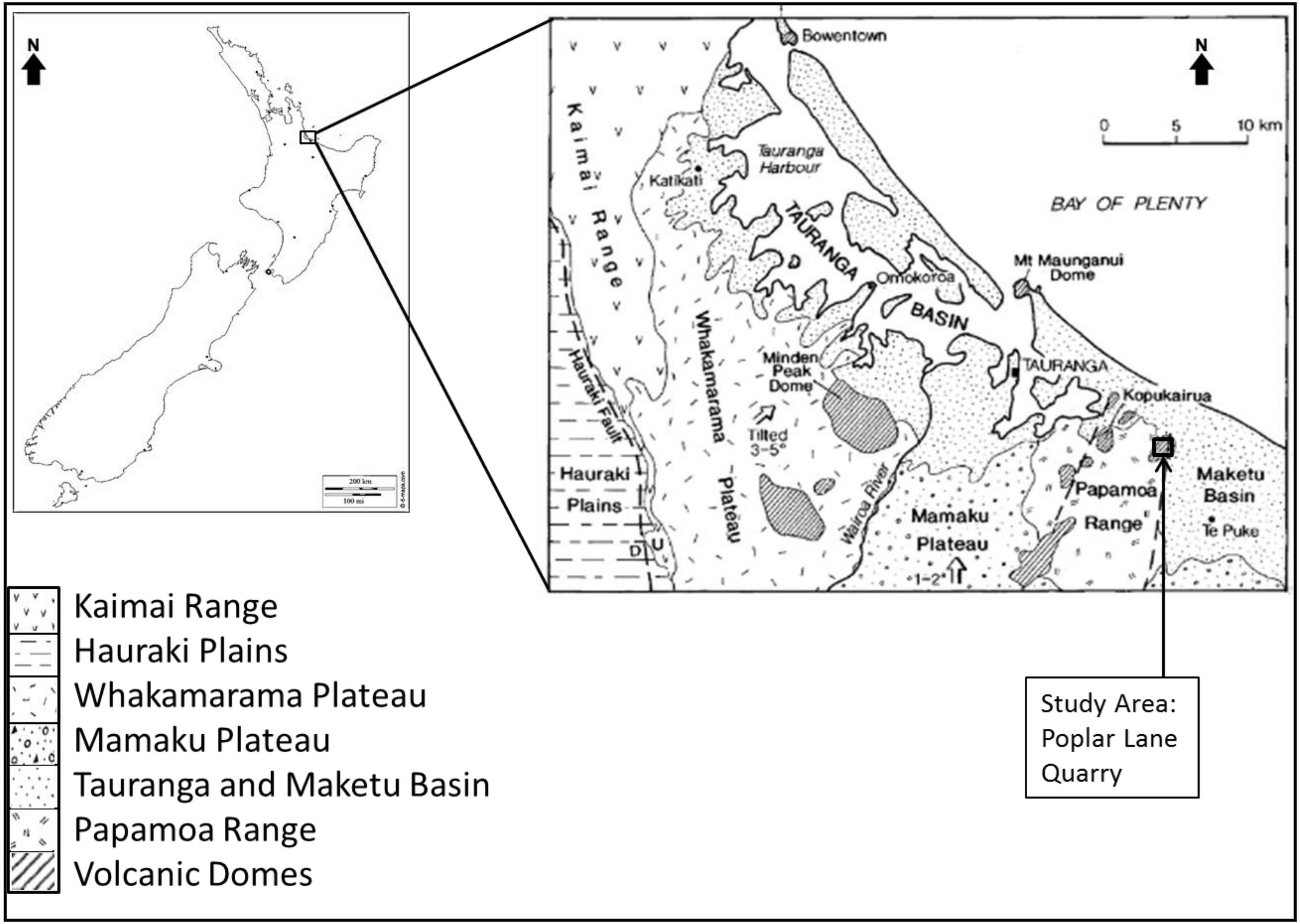

Figure 2.1 *Adopted from (Oliver, 1997) Location Map of Physiographic units within the Tauranga Basin originally from Briggs et al. (1996) – New Zealand map extracted from d-maps (2016).*

2.2.2 Local Setting - Geology of Poplar Lane Quarry

Poplar Lane Quarry is located in the Papamoa Ranges and developed in Otawa Volcanics. PLQ's aggregate source is from the porphyritic andesite which is massive to jointed and fractured (Hudec et al., 2008). The andesite comprises two lava flows, one being grey and the other brown in colour (Figure 2.2). There is no compositional or quality difference between the two lava flows. The andesite is fine-grained, glomeroporphyritic and hypidiomorphic, some are granular rock with sub-pilotaxitic to sub-trachytic texture (Bartley et al., 2007).

Bartley et al. (2007) suggested the andesite matrix consists up to 60% of microlite crystals (0.07mm) of plagioclase, orthopyroxene and opaque iron/titanium oxides, with Hudec. et al, (2008) further stating that the plagioclase was elongated and simply twinned, with the matrix mostly comprising devitrified volcanic glass. The matrix is generally randomly orientated with some local swirl and zone alignments indicating lava mass flow and fluid flow respectively. The rock contains phenocrysts up to 40% of euhedral to subhedral plagioclase (0.6mm), euhedral to anhedral orthopyroxene (0.4mm) and opaque iron/titanium oxides (0.1mm) (Bartley, 1979). Hudec et al. (2008) found minor concentraions of hypersthene/augite crystals and plaigoclaose within the lithis clasts, which were up to six times larger than other phenocrysts (Figure 2.3). Albite-oligoclase, which thought to be present as twinning was evident in the plagiolcase; this also exhibited occasional zoning indicating slow cooling which occured before the eruption. Ragged edges of some of the phenocrysts indicate rotational abrasion during flow and emplacement.

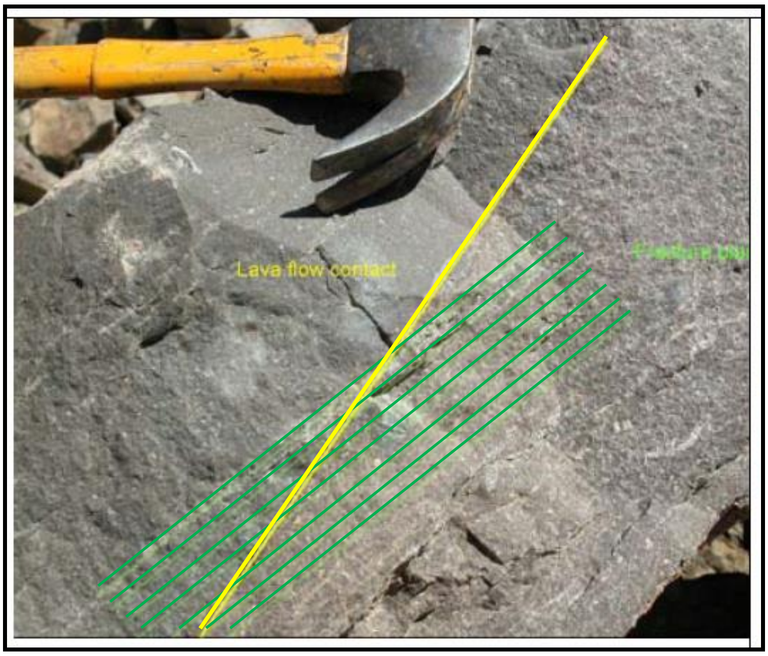

Figure 2.2 Contact of two andesite lava flows (yellow line) and fracturing pattern and orientation (green lines). Adopted from Hudec, Fulton, & Pidwerbesky (2008).

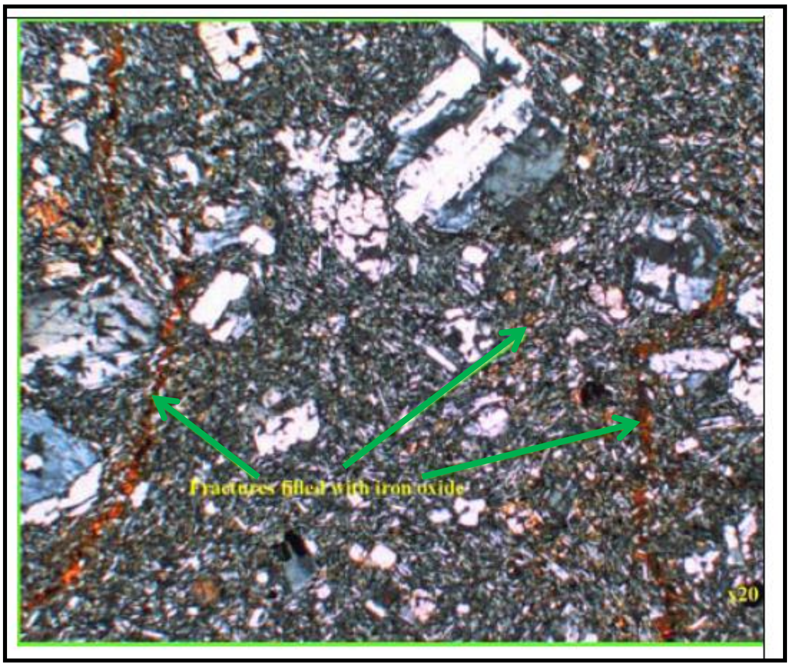

Figure 2.3 Thin section photomicrograph of PLQ porphyritic andesite. Green arrows indicate factures filled with iron oxide staining Adopted from Hudec, et al. (2008)

Bartley et al. (2007) conducted a study on four aggregates from the North Island of New Zealand. Each aggregate was studied for its mineralogical and chemical properties. PLQ was included in the study and the following observations were made;

- the fresh samples of the andesite rock showed evidence of fracturing through the groundmass and a yellow-brown staining within the plagioclase microlites, which is confirmed in a photomicrograph from Hudec et al. (2008) (Figure 2.3).
- As the weathering increases, so too did the fracturing, staining and clay-in filled veins. Hudec et al. (2008) stated that due to the nature of the facturing, the cross cutting flow lines (Figure 2.2 and 2.3), and the in-filling of devitrified glass and other minerals it is likely that fracturing occurred shortly after emplacement of the lava flow while it was still hot. Goethite and opaques accumulated along the fracture boundary.
- The alteration of the orthopyroxene phenocrysts occurred at a much slower rate than that of the plagioclase alteration.
- There was little difference in the PLQ aggregates weathering between the weathered and partly weathered sample. The smectites in the fresh rock, identified by XRD analysis, increased with progressive weathering and showed evidence of altering to kaolinite and halloysite.

Bartley, et al. (2007) reported that a clay index (CI) test was conducted on three samples of aggregate from PLQ, and values varied depending on weathering; fresh (CI = 1.2), partly weathered (CI=5.4) to weathered (CI = 6.5). The PLQ samples showed the smallest increase in CI over the various weathered samples.

2.3 NZ Road Design

Since 1963, several sets of guidelines have governed the design of pavements in New Zealand. Currently pavement design is governed by AUSTROADS *Pavement design: a guide to the structural* *design of road pavements* (Austroads, 2004), which dictates the design parameters that are to be met including drainage and aggregate specifications. It is based around the "linear elastic layer" theory, which assumes that the function of vehicle loading causes compressive strain in the subgrade, and that compressive elastic strain is roughly proportional to the permanent strain. The accumulation of permanent strain leads to rutting (Arampamoorthy & Patrick, 2010).

The general design of most roads constructed in New Zealand, dictates the following layers; the bottom-most layer is the subgrade, which is followed by the sub-base and basecourse, and sealed with a final layer of a bituminous surfacing. The subgrade is either in-situ or modified. The sub-base is a layer of lower quality aggregate and is generally unbound. The basecourse layer comprises unbound granular material and the final layer is a thin asphalt or chip seal. The principal function of the basecourse is to reduce stresses and strains from vehicle wheel loading, into the subbase and sub-grade (Siripun, et al., 2010). New Zealand pavement design lives are usually at least 25 years, with most roads lasting up to 50 years (Arampamoorthy & Patrick, 2010).

2.4 Basecourse Failure Mechanisms

2.4.1 Terminology

Currently basecourse material is tested for properties such as weathering, gradation, plasticity, and durability, but these empirical tests do not express the importance of cyclic loading from repeated traffic and do not sufficiently characterise the dynamic response of the basecourse to loading. It is this response which is ultimately responsible for basecourse failure. A major function of the basecourse material is to distribute stresses, introduced by wheel traffic loading, throughout the pavement so that stresses do not undermine the structural integrity (displacement or excessive deformation) of the subgrade (Figure 2.4).

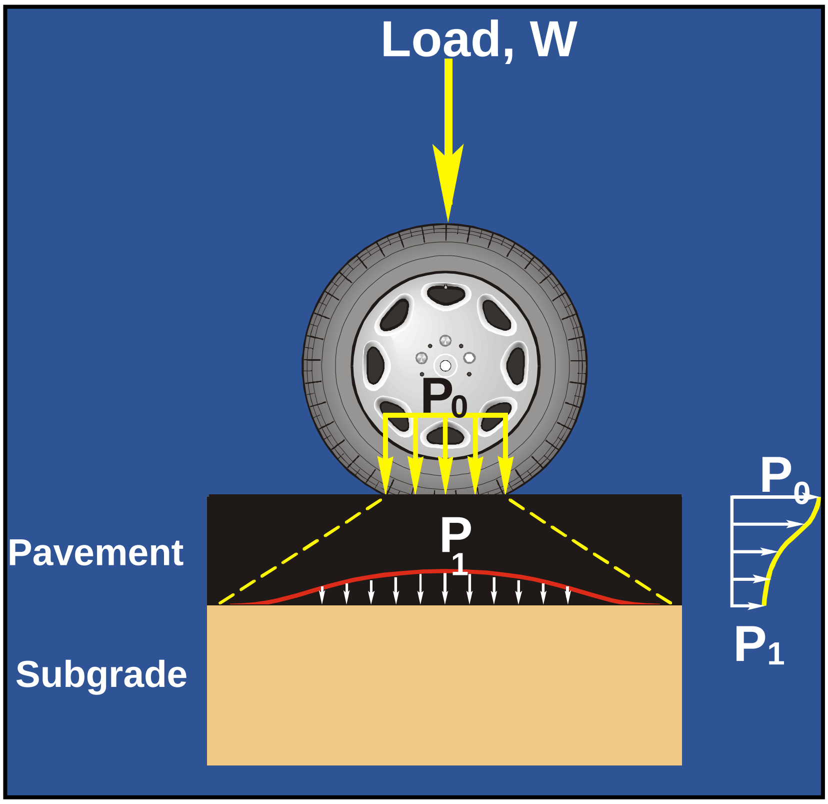

Figure 2.4 Distribution of loading (stress) thought out the pavement layers.

Researchers characterized the deformation response by describing a recoverable (resilient) deformation and a residual (permanent) deformation (Lekarp, 1997). Resilient modulus can be described as the elastic, non-linear, recoverable behaviour when a basecourse undergoes by cyclic loading. It is a measure of the resilient (recoverable) stress, strain and flexibility of an unbound pavement. Permanent deformation occurs when the plastic strain accumulates and the material rearranges into a stronger structure or fails, as is the case when rutting occurs. The resilient deformation recovers after each load whereas permanent deformation accumulates.

During loading, no permanent deformation, which could lead to shoving, should occur within the basecourse layer during the distribution of stresses. Unbound aggregate can be characterised by the resilient modulus which expresses the materials stiffness, but this does not necessarily predict the performance of the material (Englund, 2011). To improve the characterisation of the basecourse, the specification should include both the resilient modulus and the permanent deformation, this further characterises the dynamic behaviour of the material to determine its susceptibility to pavement distress such as rutting and flexural cracking.

2.4.2 Factors Effecting Pavement Deformation - Permanent and Resilient

Uthus (2007), cited from Lekarp (1999), comments that the resilient modulus, and permanent deformation, is affected by a number of factors including; stress, density, moisture content, fines content, grading, aggregate type, number of load applications, load duration, frequency and load sequence. All of these variables can be measured and are important in helping identify the major mechanisms contributing to pavement failure. A detailed literature review of these factors can be found in Appendix B.

Three dominant factors were identified as being of most importance for this research, they include the moisture content, fines content and gradings and are detailed below:

Moisture Content

At the Road and Railway Engineering Section of the Delft University of Technology Araya (2011) investigated the mechanical behaviour of unbound granular base material as a function of moisture content and degree of compaction. It was found that moisture content had a greater effect on the behaviour of the material than that of the degree of compaction.

Saarenketo et al. (2001) researched the strength and deformation properties of unbound granular material and the factors which effect the seasonal variation in its performance. Most of the research was conducted at the Tampere University of technology laboratory where material was subjected to cyclic loading at varying moisture conditions. It was found that deformation of the basecourse occurs rapidly under saturated conditions specifically during freeze thaw cycles. When saturated, the increase of pore water pressure caused by the dynamic loading from vehicles decreases the effective stress between the particles resulting in plastic deformation. Saarenketo et al. (2001) concluded that the degree of permanent deformation is a function of the suction properties controlled by the fines content of the aggregate, but it can also be influenced by the chemical properties of the material. Although freeze thaw is not a noted issue in the Bay of Plenty, it is important to note the moisture and fines can affect the performance of a basecourse.

Alabaster et al. (2015) studied the effects of water on chipseal and basecourse of high traffic volume roads at the NZTA CAPTIF track in Christchurch. Three basecourses with varying degrees of moisture sensitivity (sensitive, average and non-sensitive) were used, and sealed with primed and unprimed grade 3 and grade 5 chip. The three basecourses were alluvial greywackes sourced from the Fulton Hogan Miners Rd quarry and Isaac's quarry in Christchurch. They were graded to an M/4 AP40, AP20 and an M/4 with added fines respectively. They all had differing behaviours under saturated conditions even though all three were from the same geological source. The results highlighted that the permeabilities did not correlate well with the Repeat Load Triaxial (RLT) tests conducted, and the TNZ M/4 basecourse which was expected to perform the best performed the worst. It was suggested that the gradations specification move away from the M/4 specification and introduce denser gradations as used in Australia. Although these are more difficult to dry before sealing, they do provide the benefit of having long term rutting resistance.

Arnold et al. (2007) cited in their report that Dodds et al. (1999) observed an increase in pore water pressure when a material had a higher fines content. Stevens & Salt (2011) investigations found that pavement failure due to shoving, even when the drainage was adequate, could be attributed to the long term degree of saturation. Shoving is a result of plastic deformation which occurs perpendicular to the direction of traffic. The pavements that failed through shear instability (shoving) were attributed to the long term saturation of the basecourse. These saturated basecourses tended to be gap graded in the sand fraction, therefore Stevens & Salt (2011) proposed that a tighter grading control be introduced to the M/4 specification.

From the literature it can be concluded that moisture content plays an important role in the performance of a basecourse material, which is also a function of many other factors which could contribute to road failure, limiting the likelihood of only one mechanism causing failure. These factors in conjunction with moisture can cause permanent deformation. It can also be noted that an incorrect grading of a basecourse is often highlighted as a contributing factor to failures when moisture is a concern.

Fines Content and Grading

Arnold et al. (2007) investigated the rutting performance of one basecourse by using repeat load triaxial (RLT) tests and rut depth modelling. The objective of the research was to determine the extent to which aggregate gradings could be altered without changing or adversely affecting the rut depth of a pavement. In previous research it was revealed that aggregate with more fines and were wet have lower strength when compared with coarser gradings. Opposite effects were observed when the basecourse was fine and dry or fine and modified.

Arnold et al. (2007) used the Talbolt's n-value to describe the gradings of an aggregate; n-values> 0.5 are coarse gradings and n-values < 0.5 are fine/dense gradings. The Talbolt's grading curve represents the particle size distribution and is represented by the value of the exponent n in the equation (Equation 1):

$$P = 10\left(\frac{d}{D}\right)^{n}$$

P= % passing sieve d

d= sieve size (mm)

D= maximum particle size (mm)

n= integer - range 0.3 for finer gradings and 0.6 for coarser gradings

NZTA targets an n-value for a basecourse aggregate of between 0.4 and 0.6 although the average range internationally is between 0.3 and 0.6 (Figure 2.5).

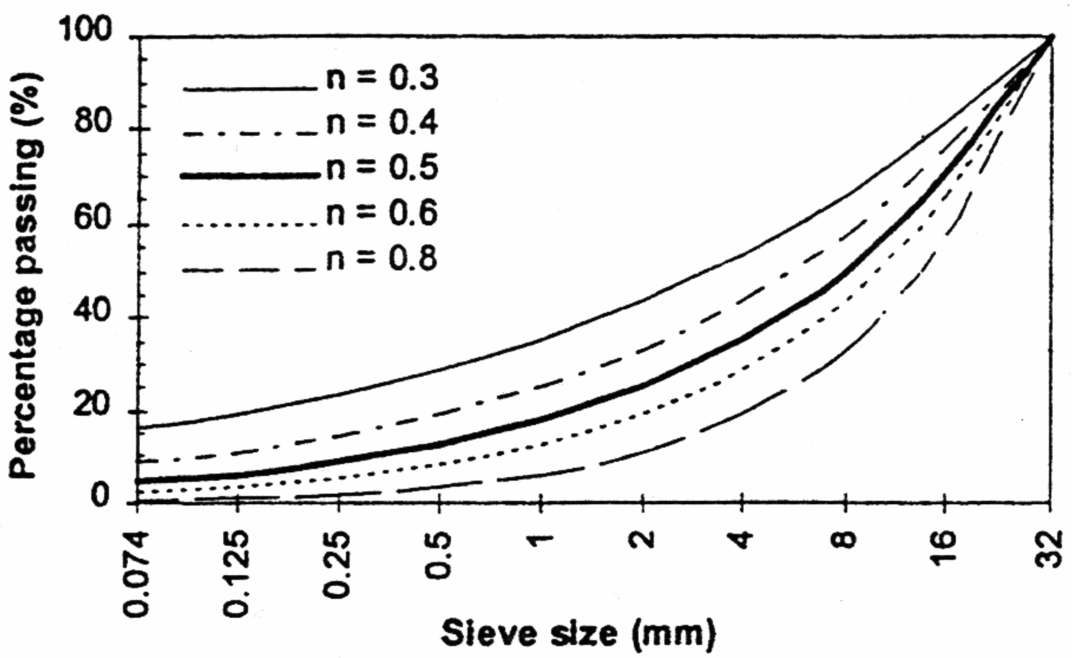

Figure 2.5 Aggregate grading curves expressed in Talbot's n-value. N=0.3 represents a finer grading, n=0.8 represents a coarser grading. Test by Belt (1997) extracted from Arnold, Werkmeister, & Alabaster (2007).

The RLT tests conducted on Canterbury Pound Rd M/4 basecourse concluded that the best performance in wet conditions had a grading n-value of 0.8 (Arnold et al., 2007), and the best performance in dry conditions had an n-value of 0.3. These tests also show that the Talbolt n-value may vary by 13% without affecting the result on rutting. The coarse grading n-value of 0.8 in wet conditions is much higher than the NZTA target of approximately 0.5.

Dense graded basecourse is described by Arnold et al. (2007) as a material where each particle size fits neatly into the space left by the next particle size. These particles interlock and fewer voids are present, which ultimately increases the strength and stability of the basecourse. Arnold et al. (2007) suggest that roading authorities generally target a denser grade because of ti's strength and stability from the interlocking particles and ultimately fewer voids than a coarser mix.

Arnold et al. (2007) cited a number of studies in the report that focused on the varying opinions for the most suitable n-value. As the n-value represents the particle size distribution it is beneficial in determining the ultimate grading for an aggregate. The following is a summary of the research reports; Lay (1984) indicated that the n-value should range from 0.45 to 0.5 for better compaction, whereas Bartley (2007) was of the opinion that the n-value should be 0.35 as fine materials compact freely. Thom and Brown (1988) concluded that the resistance to permanent deformation decreased with increasing fines content in limestones, based on the assumption that the entire fines fraction does not fit readily into pore spaces and act as lubricating particles between stones. Belt et al. (1997) conducted a number of RLT tests on a number of different aggregates with varying n-values. It was found that the lowest permanent deformation occurred when the n-value was 0.4 which is less than the theoretical maximum density grading of n=0.5. Van Niekerk (2002) found that an unbound granular material performed better when the gradings were balanced rather than uniformly graded. Barksdale (1972, 1991), Thom & Brown (1988) and Dodds et al. (1999) all concluded that an increased fines content increased the degree of deformation in RLT tests.

Bartley (2007) researched the factors that control the density of unbound granular aggregate, including the particle size distribution effect on density, compaction and performance of the pavement. The extent of compaction is measured by the moisture content and maximum dry density (MDD). The maximum dry density is of an aggregate is the highest density obtainable, this value si obtained by apply a particular compactive effect at differing moisture contents until the maximum is achieved. Samples were prepared to match grading curves with n-values between 0.25 and 0.55 with the optimum grading at maximum dry density found to be 0.33 and 0.39. Examination of test results found excessive rutting occurred soon after construction which indicated densification of the basecourse. Densification was found to occur when the total void content was greater than 15%. It was recommended that the target particle size range be reviewed. Bartley (2007) believed that deformation could be avoided if the basecourse was compacted to a high degree of density, not less than 98% of the maximum dry density (MDD), before the road was opened. Bartley (2007) recommended the grading exponent be kept to an n-value of 0.35. This would increase the amount of fines passing the 75µm to 11%, which is 50% more than the current standard allows (Stevens & Salt, 2011).

In summary, the resilient modulus and permanent deformation are affected by a number of factors. It is important to determine which factor affects a particular material the most, and to limit any variables to ascertain how and why a pavement fails. The majority of the research has been conducted around moisture effects, fines content, grading control and load applications.

2.4.3 Basecourse Degradation

Basecourse degradation is the failure of the aggregate used in a pavement and not the pavement it's self although it is a contributing factor. Minor (1959) stated that earlier work on aggregate degradation related the performance of aggregate to its mineral composition. Paige-Green (2004) found deterioration of aggregate has been investigated in the USA since 1880, and since 1990 issues with basic crystalline rocks were reported in both the USA and Europe. These issues were related to the presence of secondary minerals (clays) within the material that were inherent before utilisation. Paige-Green (2007) conducted a study on road aggregate that deteriorated in-service due to crushing processes despite the material meeting local standards. The durability of the aggregate was tested using standard methods, as well as introducing non-standard test methods. The study found that although it was relatively easy to identify weathered material road failures due to aggregate degradation were still recorded. It was thought that weathered material was included in the supply of aggregate even though it passed the necessary standard testing; this resulted in the reliability of the standards being questioned and higher quality material being transported from further afield.

Aughenbaugh et al. (1963) conducted a study on how compaction influenced basecourse aggregate degradation. In multi-layer pavements it was found that the upper layer breakdown occurs during the first compaction. The breakdown lessens until after the eight pass of the compactor when minimal degradation occurs. As the pavement layers increase, the breakdown decreases and the type of compaction energy has an influence on the degradation (Aughenbaugh, et al., 1963).

Henderson et al. (2011) concluded that compaction of cohesion-less granular aggregates has a small effect on the orientation of the particles.

Aggregate degradation may be defined as the breakdown of particles into smaller pieces through chemical or physical means (Pintner, et al., 1987). The crushing process in the plant causes the breakdown of aggregate into smaller sizes and produces fines. This is different to the handing process which causes fines due to abrasion and impact from compaction; the two are substantially different (Pintner, et al., 1987). It has been concluded by Aughenbaugh et al. (1966) that no one particular test can be used to evaluate the production of fines during handling. Pintner et al (1987) developed a three part test to determine the quantity of fines produced during processing. Each stage/part tested crushing, handling and placement respectively. There was poor correlation between the fines produced and the Washington Degradation Test (Washington State Department of Transportation, 2009), and it was stated that this three part method should only be used to determine the maximum number of fines produced for each stage.

2.5 Clays in Aggregates

2.5.1 Clay Terminology and Minerals

Clay minerals are layer silicates and are formed from the process of weathering. More specifically the formation of clay minerals can be attributed to three formation mechanisms (inheritance, neoformation and transformation) and three geological environments (weathering, sedimentary and diagenetic-hydrothermal (Eberl, 1984). Eberl (1984) based these three formation mechanisms on the ideas of Esquevin (1958) and Millot (1970), who allowed for a possible nine origins of clay minerals derived from the three formation mechanisms and the three geological environments.

There are typically five main types of clays; Kaolinite, Illite, Chlorite, Vermiculite and Smectite (Figure 2.6). Each clay type has a unique structure (layer type) and properties (Table 2.1). The layers are a combination of tetrahedral and octahedral sheets, namely silica tetrahedron and aluminium octahedral. The 1:1 layer minerals have one tetrahedral sheet and one octahedral sheet; those minerals with a 2:1 layer type have two tetrahedral sheets which sandwich one octahedral sheet (Sposito, 2008).

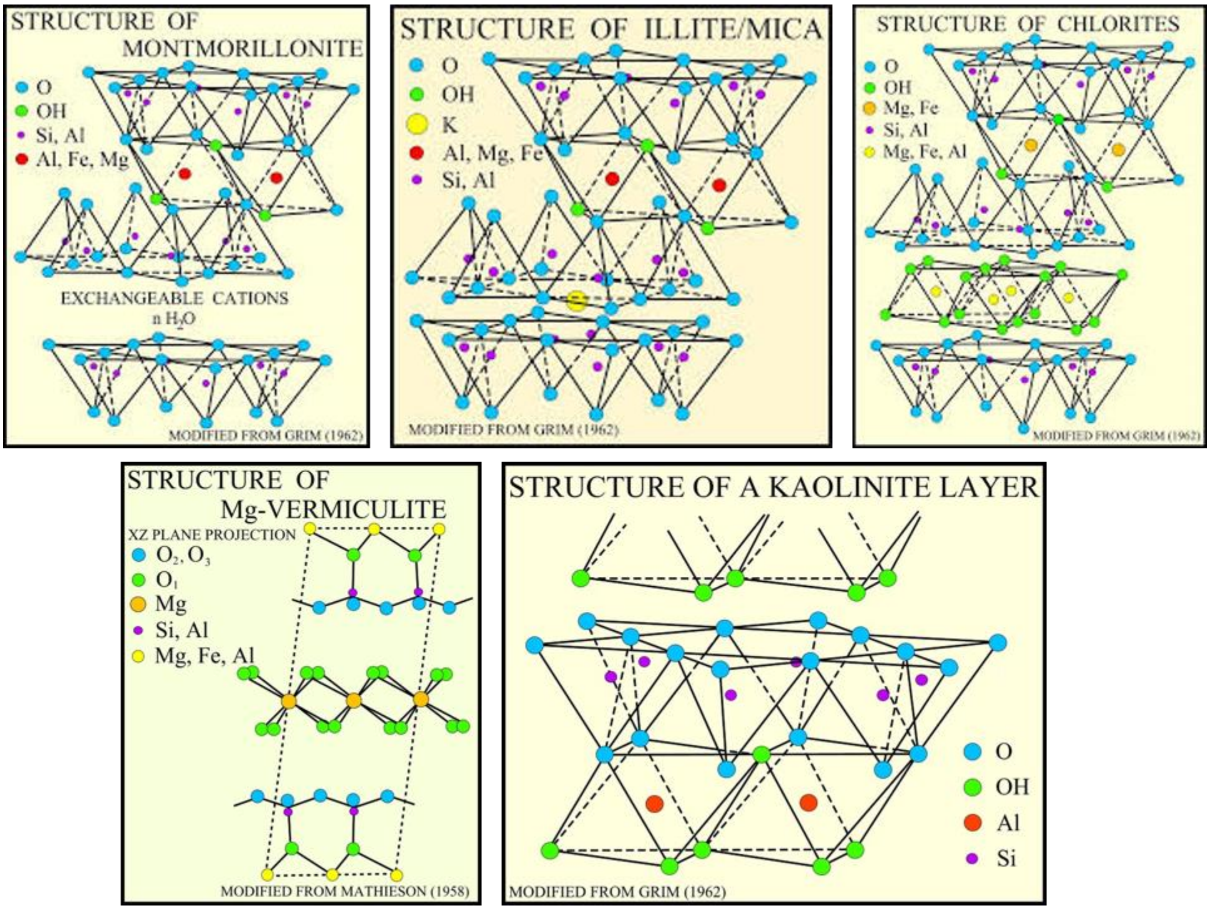

Figure 2.6 Clay group structures. Montmorillonite structure represents the Smectite group. Extracted from U.S Geological Survey, (2016)

Table 2.1 Clay Mineral Groups adapted from Sposito (2008)

Group	Layer Type	Layer Charge (x)	Type of Chemical Formula
Smectite	2:01	0.5-1.2	Mx[Si8]Al3.2Fe0.2Mg0.6O20 (OH)4
Kaolinite	1:01	<0.01	[Si4]Al4O10(OH)8 . nH2O (n= 0 or 4)
Illite	2:01	1.4-2.0	Mx[Si6.8Al1.2]Al3Fe0.25Mg0.75O20(OH)4
Vermiculite	2:01	1.2-1.8	Mx[Si7Al]Al3Fe0.5Mg0.5O20(OH)4
Chlorite	2:01:01	Variable	(Al(OH)2.55)4[Si6.8Al1.2]Al3.4Mg0.6O20(OH)4

Note: [ ] indicates tetrahedral coordination; kaolinite n=0 and Halloysite n=4; H_2O is interlayer water; M = monovalent interlayer cation.

The plasticity of a material is dependent on a number of factors such as mineralogical composition, particle size distribution, organic substances and additives, but for the majority of aggregates the clay content and type play a major role in the plasticity. Plasticity of a soil is defined by the deformation of a substance under an applied force, the more plastic a material is the more it can be deformed without failure. The soil is tested under different states of moisture which allows the clay particles to behave different. As the moisture content increases so does the plasticity until a point at which it begins to fail. Particular types of clay allow for a higher plastic limit to be reached where as others such as those from the Kaolin group are relatively non-plastic (Andrade, et al. 2011).

2.5.2 Smectite Group

Smectite clays have a number of interesting and unique characteristics, and understanding the physiochemical properties aids the understanding of how smectites influence the performance of aggregates. Smectites form in layers with weak bonds between the layers; these layers consist of negatively charged oxygen atoms interspersed with positively charged cations in specific positions (Na, Ca, Mg, and/or H). The typical structure of the smectite atom consists of one alumina octahedral sheet between two silica tetrahedral sheets forming a 2:1 phylosillicate with weak van der Waal forces between the layers (Odom, 1984 and Morris & Marek, 2009). A unique property of smectite minerals is the interlayer cation exchange and hydration, as well as the interlayer surface hydration (Odom, 1984). Additional information regarding the expansion of smectite clays can be found in Appendix B

Montmorillonite, the most common smectite clay, can expand by several times its original volume when it comes in contact with water. The montmorillonite smectite found within the PLQ rock is Na-rich, which implies that it will undergo osmotic swelling (double layer expansion) which causes a much higher basal spacing, and is furthermore dependant on the water and salt concentration of the system. Other smectite minerals expand due to crystalline swelling which stops at a specific hydration point.

Naturally occurring sodium montmorillonite can display high plasticises up to three times higher than other clays, whereas calcium montmorillonite has a lower plasticity index generally in the mid-range (Bain, 1971).

2.5.3 Kaolin Group

The Kaolin group is made up of the following four minerals; kaolinite, dickite, nacrite and halloysite. All the minerals in this group have the formula $Al_2Si_2O_5$, and Halloysite varies with the addition of water molecules has the formula $Al_2Si_2O_5(OH)_4 .2H_2O$ (Ruiz, 2006). The most common parent mineral from which kaolinites develop from is potassium (K) feldspar and muscovite. The following chemical formula shows the transformation from K-feldspar to a kaolin mineral;

$$2\ KAlSi_3O_8 + 3\ H_2O - Al_2Si_2O_5(OH)_4 + 4\ SiO_2 + 2\ K(OH)$$

Kaolin is a commonly found mineral and a product of advanced weathering. It differs from smectites because it is a 1:1 dioctahedral phyllosilicate sheet layer mineral, with one layer consisting of an alumina octahedral and the others a silica tetrahedral sheet interspersed by oxygen atoms with repetitions bonded together by hydrogen bonds (Miranda-Trevino & Coles, 2003). Kaolins are the least reactive clay and are non-expansive due to the high molecular stability, and the well-packed structure allows the mineral to wit stand layer separation from the exposure to water and has a low compressibility.

Kaolinite minerals are generally non plastic but plasticity indices can vary according to grain size and some alluvial kaolins have a plastic nanture. Halloysite calys are genrally non-plastic but can have slightly higher plasticities than other kaolinite clays (Bain, 1971).

2.6 Additional Aggregate Test Methods

2.6.1 General Summary

Due to the structural and chemical nature of some material, it may be necessary to introduce additional testing to ascertain properties that are not currently tested in the NZTA M/4 specification.

The assessments discussed below include durability studies, as well as mineral assemblage and concentrations and determinations.

1. Repeat Load Triaxial (RLT) test is used to simulate traffic loading by applying repetitive loading to determine when pavement failure occurs due to rutting. Arnold et al, (2008) developed a new method in 2005/2006 which introduced lower testing stresses so that samples are able to withstand most stages of the test and still produce the necessary data. Three other methods were investigated, but these were found to be unfavourable, as stresses were either too high or did not accurately mimic the predicted traffic loading. In August 2013 NZTA (2013) included in the 'state highway maintenance contract' that in addition to meeting the M/4 specification, all material used in the construction of projects must meet the Repeat Load Triaxial test criteria as specified in the document NZTA T/15 (NZTA, 2014). This requirement was specified for sites where the design traffic loading is greater or equal to five million Equivalent Standard Axles (ESA).

2. X-ray Diffraction (XRD) analysis is commonly used to analyse clay minerals and has been discussed throughout this review. XRD has been used in conjunction with petrography to analyse the mineral structure of the aggregate. It is important that the preparation of a clay sample is conducted effectively as the plately nature and orientation of the clay mineral can have an effect on the diffraction peak (Lyland et al, 2014). XRD is used to analyse and measure the molecular structure of a crystal; it is measured in counts per second. Peak intensity of the smectite alteration averaged 101 cps (counts per second) and ranged from 88 to 116cps. The higher values indicated a higher degree of alteration and vice-versa for the lower values. Sordon et al. (2001) state that X-ray powder diffraction is the best method to identify and analyse the minerals within clay rich rocks; this is because with this technique all minerals can be identified individually, which is a major advantage when conducting a quantitative analysis. It must be stated that the chemical and structural

characteristics of clay minerals prompt challenges when computing a quantitative analysis using XRD (Sordon, et al., 2001). These difficulties arise from the differences in the intensities of the mineral reflections, Sordon et al.(2001) found that the clay minerals where less reflective than the non-clay minerals which would result in the clay minerals being more difficult to distinguish when using XRD.

3. Paige-Green (2007) utilised 16 methods to test the durability of 12 basic crystalline samples. It was found that the clay content, particularly smectite content, did not correlate with the performance of the material, and that the existing tests did not identify those minerals that were expected to cause the material to fail in-service. Paige-Green (2007) proposed that the following methods were beneficial to determine the durability of a material: petrographic and mineralogical analysis, Durability Mill Index, 10% Fines Aggregate Crushing Test (FACT) or Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV) or Modified AIV, and Glycol soaking test. Petrographic and mineralogical analysis and Glycol soaking were utilised in this research.

2.6.2 Ethylene Glycol Soaking

Ethylene glycol is a substance which reacts with the montmorillonite smectite group, causing it to expand. This may be a similar response to the smectite clays in the field as they undergo years of wetting, drying and freezing, causing the breakdown of the aggregate and ultimately road failure. A number of ethylene glycol test methods have been developed. NZTA proposes an Accelerated Weathering test, which follows the test method NZS 4407 as Test 3.10 *Crushing Resistance* with the addition of soaking the material in ethylene glycol (EG) for 21 days and correlating the fines collected to that of an unsoaked sample (NZTA, 2015). This method was developed by using research conducted in South Africa on basalts and diorites.

The behaviour of clay minerals differs between clay types when exposed to Ethylene Glycol (EG). Table 2.2 details the expansion properties of some of the most common clay minerals, which emphasises the variations in the expansion capacities and response to EG.

Table 2.2 d Spacing on {001} for Clay-Type Mineral (Å)

MINERAL	UNTREATED	ETHYLENE GLYCOL	HEATED TO 550ºC
	(d- spacing)	*(d-spacing)*	*(d-spacing)*
Kaolinite	7.1	No Change	Destroyed
Montmorillonite	14 - 15	17	9.5
Illite	10	No Change	Little Change
Chlorite	7	No Change	13.2
Mixed Layer	11	12	10

Paige-Green (2007) determined that the original glycol soaking test method did not provide consistent results and therefore a revised method should be adopted specifically for road aggregate. The method proposed is outlined below:

Pieces of aggregate are placed in a tray in a fixed pattern and covered with ethylene glycol. The specimens are inspected at intervals over a number of days. After each inspection, each piece is inspected for spalling (shedding of small fragments), fracturing (splitting of the stone) and disintegration (splitting into more than 3 pieces). The optimum number of days required for the ethylene glycol to permeate through the sample was four days (Paige-Green, 2007). Paige-Green (2007) concluded that no one test is suitable to determine the durability of a material and that a number of tests be required. It is particularly important to include a test that accurately and efficiently identifies deleterious minerals which can cause the degradation of the aggregate in-service. The use of an ethylene glycol test and a strength test (indirect tensile strength and point load strength) may be the most beneficial to determine the durability (Paige-Green, 2007).

2.6.3 Stabilisation of Basecourse Aggregates

There is limited research on advancing or designing basecourse material that may contain expansive clays, however there is research specifically focusing on subgrades with expansive clays.

Cement has been used for many years as a stabilising agent, and is not dependent on the aggregate properties to bind the aggregates. The addition of cement to clay soils reduces the hydraulic conductivity significantly, due to the reduction of the macro-pores (Sasanian , 2011).

The inclusion of lime in a basecourse material has a number of beneficial properties, especially for those materials that do not consistently perform and may contain deleterious clays. Lime stabilising alters the material in the following ways: increases strength and stability, reduces swelling capacity, and reduces plasticity and improved compactability (Department of Transport and Main Roads, 2012). Lime stabilising is beneficial for materials which have a Plasticity Index (PI) of greater than 10%.

In 2006 Werkmiester & Steven conducted a number of RLT test on the PLQ basecourse to determine which suitable modifiers were viable in basecourse material for pavement construction. The results concluded that cement can be used, and lime is a suitable additive. Foamed bitumen was deemed unsuccessful, but with improved grading (as the material was too coarse) and moisture control it is a possible alternative (Werkmeister & Steven, 2006).

Caunce's (2010) research focused on effective roads built on expansive soils. Although some of the assessments could not be used specifically for basecourses, they are valuable in understanding how the expansive clays affect the subbase and offer ways to effectively remedy or stabilise them. Lime and Portland cement are the most common stabilisers but there are a number of traditional (lime and cement and fly ash), by-product (kiln dusts and other by-products), and non-traditional alternatives (sulfonated oils, potassium compounds, ammonium chloride, enzymes, polymers) available (Petry & Little, 2002). Most traditional and by-product stabilisers rely on calcium exchange and pozzolanic reactions, and non-traditional stabilisers rely on unique exchanges which differ for each product/method. More specifically, smectite clays, which exhibit expansion with changes in water content, act more like illite clays when introduced to potassium. These illite-like clays are less active (Petry & Little, 2002). A study by Chen (2004) concluded that lime, compared with Portland cement and lime/cement, showed the greatest improvement for compaction, California Bearing Ratio (CBR) and swelling of clays.

Chittoori et al. (2013) investigated the leaching cycles of stabilised (cement and lime) clays and came to the conclusion that some leaching did occur, but that was insignificant in relation to strength loss. Materials with high Plasticity Index (PI) values and a high percentage of montmorillonite are more susceptible to the adverse effects of the leaching. Chittoori et al. (2013) recommended ensuring the inclusion of the montmorillonite percentage when calculating the percentage of stabiliser to be added, as this generally results in a higher dosage.

2.7 Review of Basecourse Specifications

This chapter details the comparisons and correlations to the current and proposed NZTA M/4 basecourse speciation. It includes a history of the specification and the introduction of test methods. A summary of the current source and production property testing regime is tabulated, any changes included in the draft speciation. A detailed description of the current and draft specifications as well as the research and reasoning behind these changes can be found in Appendix C. A summarised version of all the test methods mentioned in this chapter can be found in Appendix D.

2.7.1 Specification Background

The use of basecourse aggregates in New Zealand is governed by the NZTA Specification for Basecourse Aggregate (TNZ M/4, 2006) and supported by the Notes to the Specification for basecourse aggregate (TNZ M/4 N, 2006), which requires compliance with a number of tests to ensure the basecourse source and production process is suitable. Multiple reports of permanent deformation of unbound granular pavements (basecourse) occurring regularly in New Zealand (Paige-Green 2007, Hudec, et al. 2008, Stevens & Salt 2011) highlight the importance of a reliable

M/4 NZTA specification basecourse aggregate for the construction of roads. Inferior material produced to a lower standard is readily available, but its use in certain areas may results in permanent deformation.

Roading specifications in New Zealand have evolved over time. It is postulated that early road construction would have been based on the United Kingdom methods of Telford (1751 -1834) or Macadam (1756 -1836), with both placing emphasis on good drainage (Ferry & Major, 1987). As vehicle designs progressed and traffic volumes increased, it was apparent that knowledge and finance were lacking, and this led to the establishment of the Main Highways Board (MHB) in 1924. Ferry & Major (1987) outlined the MHB's first "skeleton specification", produced in 1925, and it appears that this specification was merely a best practise guide to be adopted, but that was not strictly enforced. The grading requirements listed four fraction sizes from 34mm and below, with an emphasis on the larger fractions.

In 1936, the NZ Society of Civil Engineers (NZIE), now the Institution of Professional Engineers New Zealand (IPENZ), released a new specification. This was the result of an investigation into rural roads; because with the improvement in technology more information and records were available. The grading requirement allowed for a larger percentage of fines than the previous specification. This would have allowed the material to be easily laid and appear sandy. With the increase in fines the material would be susceptible to moisture damage, especially if expansive clays were present. The idea behind the introduction of greater fines was to produce a material that would have cohesive fines, but which would not shrink when dry but still have ease of workability (Bartley, 1987).

In 1954 a new speciation, NRB B/2, was released by the National Roads Board (NRB). It was similar to the NZIE 1938 specification, but it limited the amount of fines, particularly in the sand and silt fractions, so as to improve the moisture sensitivity of the basecourse. Atterberg Limits had become more recognised and a PI of 3% 'PI of material passing the 52mesh shall not exceed 3%' was introduced. In 1958, a revised specification was released, but Bartley (1988) explains that the reason for this was unclear.

The NRB M4 was released in New Zealand in 1973 in response to what the industry described as apparent excessive pore-water pressure in pavements. This focused attention on moisture and saturation levels as well as permeability (Bartley, 1987). It was also noted by Bartley (1988) that, although Atterberg limits were an important and essential tool in measuring the properties of the fines, different technicians could easily generate different results on the same sample. Following this, the Sand Equivalent (SE) test was introduced to gain a more reliable measure. In 1974, the NRB M4 was released with metric units. Following research conducted by Sameshima and Black in 1979 on the weathering of andesites and greywackes, the Clay Index (CI) test was developed to assess the proportion of swelling clays in an aggregate.

In 1980 an Aggregate Selection Chart was developed by Bartley, and further revised by a number of authors (Appendix E). The chart was used to provide a means of selecting an aggregate for its intended purpose and the conditions in which it was to perform. The chart takes into account four main criteria: plasticity, permeability, drainage and support, and special water control and should be used for river gravels or a rock that has similar compressive strength (Brennan, 1987).

2.7.2 Summary of Specifications

A detailed description of the current and draft specifications can be found in Appendix C. Both specifications are separated into two sections. The first being the source property testing and then the production property testing. Table 2.3 summaries the changes and additions between the two specifications.

Table 2.3 Summary of current and draft M/4 specifications. Highlighting the additions and changes

Test Method	Current Specification TNZ M/4 (2006)	Draft Specification NZTA M/4 (2016)
Source Property Testing		
Crushing Resistance NZS 4407:1994 Test 3.10, The Crushing Resistance Test	Under a load of 130kN record resulting fines percentage. May not be greater than 10%	If blended fines are added additional assessment must be undertaken or documentation proving performance
Weathering Quality Index NZS 4407:1991 Test 3.11 Weathering Quality Index	Aggregate undergoes a number of accelerated conditions, including boiling, ambient temperatures, drying under heat and saturation. The fines are captured and a cleanness value is determined	No Change
California Bearing Ratio NZS 4407: 1991, Test 3.15 The California Bearing Ratio Test	A sample of aggregate is compacted into a mould soaked for a predetermined number of days and tested under load	No Change
Sampling		Sampling conducted no more than 3 months prior to testing
Production Property Testing		
Sand Equivalent NZS 4407: 1991, Test 3.6 Sand Equivalent Test	Ratio between fines and sand using a settling column. Result should not be greater than 40	No Change
Plasticity Index NZS 4407: 1991, Test 3.4 Plasticity Index Test	Determines the state of a sample passing the 4.75 mm sieve. Plasticity Index (PI) is determined using the Liquid Limit and Plastic limits. The result should not be greater than 5.	Weighted clay index. The PI value will be multiplied by the percentage of the complete sample passing the 4.75 mm sieve. The result should not be greater than 40.
Clay Index NZS 4407: 1991, Test 3.5 Clay Index Test	Clay Index (CI) is determined by reacting the material passing the 75 µm sieve with methylene blue. The result shall not be greater than 3.	The CI value is multiplied by the material passing the 75 µm sieve of a complete sample. The result should not be great than 15.
Broken Faces NZS 4407: 1991, Test 3.14 Broken Face Test.	Requires two or more freshly broken faces of a sample coarser than the 4.75mm sieve and that each of the three aggregate fractions between 37.5mm and 4.75mm shall not be less than 70% broken faces	The Broken Faces content of aggregate in fractions coarser than 4.75mm shall not be less than 70%,
Particle Size Distribution NZS 4407: 1991, Test 3.8.1 Wet Sieving Test	See table 3.1 for grading envelopes	See table 3.2 for grading envelopes. Maximum allowable percentages of weight passing the sieves between 600µm - 9.5mm were increased slightly

Sand Grading Exponent NZS 4407: 1991, Test 3.8.1 Wet Sieving Test	Not Included	It measures the amount of gap grading and is the effective slope of the particle distribution in the sand size range. Calculation table provided by NZTA. The result shall not be less than 0.40.

2.7.3 Draft specification effect on the PLQ basecourse

The proposed M/4 specification was developed to ensure tighter control over what type and quality of material is classed as M/4 basecourse. The specification includes some significant changes, as well as some new tests and stricter requirements; this may now avoid the situation of materials failing in situ despite having passed all the tests required. The most notable change is the addition of the Sand Grading Exponent and the Incremental Grading Exponent (NZTA, 2012 and NZTA a, 2012).

In the past the, Plasticity Index and Clay Index values of the PLQ aggregate have proven to be inconsistent and at times the material has failed to meet the required standard; this may prove problematic if it does not meet either of the other two requirements (Sand Equivalent and Sand Grading Exponent). The PLQ basecourse has consistently met the Sand Equivalent standard and no amendments in this section have been proposed in the revised draft specification. The Sand Grading Exponent is the only other factor, should the Plasticity Index and Clay Index specification not be met, governing the suitability of the PLQ basecourse for Quality of fines. Given that there is no previous record of the PLQ material having gap grading (the SGE identifies gap grading in an aggregate), it is then unlikely that the SGE specification will hinder compliance of the PLQ aggregate with the new standards. Indeed, the material will meet at least two of the proposed four requirements, as per the new draft standards.

The SGE of the PLQ aggregate has not been addressed before and values will be calculated to determine if the basecourse falls within the specified range. The n-value which governs grading exponent is determined using the PSD value; as the PLQ basecourse falls within the specified range it is unlikely that it will not meet the required standard.

2.8 Summary of Literature Review and Testing Methodology

The geology and historic investigations indicate that the quarry is situated in a complex area with numerous flows and faults as well as the possible appearance of expansive clays. These are important factors to consider when using an aggregate for the construction of pavements as there are a number of other factors that can be affected by the geology and nature of the rock. Not only do the properties and characteristics of the materials play an important role so too does the condition in which they are inter-related.

There are a number of factors that contribute to the performance of a pavement, and from the research it can be determined that it is difficult to single out one failure mechanism as the contributing factor to poor performance. The main areas focused on in this literature review were moisture, fine aggregate content and grading of the material. These were especially important as the literature suggests smectite clays are inherent in the rock.

The clays that are of most relevant to the PLQ aggregate are from the smectite and kaolin groups. Smectite clays such as montmorillonite are highly expansive and can cause the breakdown of the aggregate whereas halloysite from the kaolinite group are non-expansive and pose less of a risk to aggregate breakdown.

This literature review also summaries the current TNZ M/4 basecourse specification and includes the changes and additions detailed din the proposed NZTA M/4 basecourse specification. The draft NZTA M/4 specification allows for tighter controls governing the use of basecourse aggregate in New Zealand. The amendments to the current standard are minor and serve to clarify the specifications and avert presence of “loop-holes”. The additions to the specification were developed from a better understanding of why pavements fail; this will have an effect on the usability of some basecourse aggregates if the material cannot meet the requirements. The PLQ test results for the current M/4 standard and the draft NTZA M/4 specification, with the additional tests, will be explored in Chapter Five and Six.

3. Chapter 3 Field Investigations

3.1 Introduction

This chapter provides a description and discussion of the field investigation research methodology and the reasoning behind this approach.

A desk top study is presented, which determined the history of the quarry, elucidated previous research conducted, and examined historic imagery of the quarry to track the progress from when it was first owned by Fulton Hogan to when this research was conducted.

Actual field investigation, which was conducted on site for this research are described. It includes fracture and joint mapping of the selected sites, the sampling of aggregate process and a review of the blasting and crushing process.

3.2 Research Methodology

3.2.1 Research Scope

The scope of this research was to conduct a detailed analysis of the PLQ TNZ AP40 basecourse to establish its most suitable application. This assessment progressed from a field investigation to laboratory analysis to determine physical properties and assess the mineralogy of the rock.

This research has focused exclusively on the PLQ Transit AP40 basecourse, with the addition of a control stone – Miners Rd Canterbury Transit AP40 basecourse. The two quarries operate independently of each other have differing sources and non-competing clients due to their locations, but both are owned by Fulton Hogan Ltd. Miners Rd basecourse is produced from alluvial greywacke and is known to perform well, it is a used as a benchmark control stone in this instance.

Historic data from PLQ was collected and collated for additional understanding of the processes and progress of the quarry. Comparisons of historic data with the results of this research allowed for the identification of trends over time.

Six samples of each of the three differing weathering grades of material currently produced at Poplar Lane Quarry were tested as Transit AP40. The three grades ranged from moderately to completely weathered and were named; G-Grade, T-Grade and C-Grade material accordingly. G-Grade is typically the material that is used to produce General All Passing (GAP) grade products, the T-Grade is the material used to produce Transit AP40 a.k.a NZTA M/4 and the C-Grade material is typically used to produce chip products. These three grades were selected to encompass the full range of material performance.

Three specific site areas, within the Southern quadrant of the quarry, were selected with guidance from the Quarry Manager and were processed (excavated after blasting and transported to the crushing plant) during the site visit.

Testing of the aggregate was conducted in accordance with the TNZ M/4 specification and for additional testing not specified in the TNZ M/4, appropriate industry standard methods were followed (refer to Appendix D). Deviations from the method/s were reported. Limiting factors included the time needed to complete all tests, and the available resources and man power requirement. To overcome this, testing was completed at the PLQ laboratory, the Christchurch Miners Rd laboratory, and the University of Canterbury. Extensive testing was required and because mechanically based test methodology is inherently time consuming, the timeframe of the research project necessitated a limit to the number of samples tested.

3.2.2 Type of Research

Applied research was adopted as the base of this research. According to Saunders et al (2003), applied research has the following purposes;

- To improve the understanding of a particular problem or research topic
- To discover new knowledge limited to the problem or research topic
- To enable the development of findings of practical relevance to the research
- To arrive at a solution to the problem.

3.2.3 Research Approach

The research approach is critical to the process of the investigation. There are two types of approaches to conducting research; inductive and deductive. The major differences between these two approaches are outlined below (Saunders et al., 2007).

Inductive Approach

- Qualitative research
- Findings of research are not necessarily generalised
- Structure of research is flexible to allow for changes
- Researcher is an integral part of the research and interpretation process
- Content of research is understood in a more profound way

Deductive Approach

- Quantitative research
- Science-based principles
- Highly structured approach
- Process of research flows from theory to data analysis
- Relationship between variables need to be explained
- Sample size to be appropriate to allow for generalised conclusions
- Researcher objective and not involved in the research process
- Control measures are practised to ensure validity of data

The research collected quantitative data, and the researcher was independent of the research process. A highly structured approach which emphasised the validity of the data was critical to this project. A detailed research plan can be found in Appendix F. A deductive approach was therefore chosen for this research.

3.2.4 Sample Size

Historic test reports were collated from 13 years of data (2003 to 2015). The type of testing conducted and the amount of each test varied over the years as yields of the aggregate produced varied. A total of 18 samples were collected; there were six samples of each of the three weathering grades of aggregate.

The three grades were extracted from the specific sites in the quarry according to the different weathering of the aggregate, which ensured that there was reliable representation of the material. These three weathering, ranging from well to completely weathered, categories were selected for full representation of the quarry, meaning its lesser quality rock to its better quality rock under the same conditions. The sample size ensured that valid statistical analysis could be conducted on the results, and that there was accurate representation of each weathering grade and rock quality within the quarry.

3.3 Desk Top Study

3.3.1 History of Poplar Lane Quarry and Aggregate

The Poplar Lane Quarry (PLQ) resource has been used as basecourse in the construction of roads in the region since 1998 (Hudec et al., 2008). The PLQ site, formerly named Maketu Quarry, was originally owned by a series of small contracting companies in the 1950's. As the Bay of Plenty region developed and urban boundaries stretched into surrounding rural areas, depletion of resources forced some of the region's quarries to close and the PLQ site became one the main sources of aggregate (Hudec et al., 2008). In 1998, Fulton Hogan purchased the Maketu quarry and renamed it

Poplar Lane Quarry. At the time of purchase by Fulton Hogan in 1998, the quarry was at RL+20 (20m above sea level). At the time of writing, the bottom of the pit is now RL-45 (45m below sea level).

In the past, some roads constructed using PLQ aggregate have experienced premature rutting, due to a variety of causes. This was unexpected as the aggregate had met and exceeded the source property standards set by NZTA. An investigation by Hudec et al., (2008) reported that the sand equivalent had reduced from 60 to 30 after the road was opened to traffic. The specified limit for the sand equivalent test is no greater than 40. This implies that the fines content had increased due to either breakdown of the aggregate or pumping up of fines into the pavement. A number of remedial measures, which were not specified, were put in place to rectify the issue. There was anecdotal evidence that fines were added during construction to aid compaction. To reduce the fines fraction in the material, improved quarrying practices were implemented in 2002, which involved weathered material being removed from the process by selective processes. The material was selected based on the three weathering grades and blasted separately to ensure the higher quality aggregate is used for the right purpose. This highlights the issue that the TNZ M/4 aggregate standards are not specific enough for the PLQ material when used as a basecourse.

A technical review of the Poplar Lane Quarry aggregate by Bartley et al. (2007) found that the basecourse met or exceeded all standard testing required by the M/4 specification, but in some applications the in-service performance of the aggregate was below expectations (Hudec et al., 2008). The report by Hudec et al. (2008) found the porphyritic andesite to contain high temperature minerals which are prone to rapid weathering, especially when influenced by the region's subtropical climate. Volcanic glass was also found in the material and has the potential to deteriorate into smectite clays; this was confirmed when clays were found after accelerated weathering tests were performed. These clays would have formed from the volcanic glass (Hudec et al., 2008). Clays were also found within the fractures of the rock (Bartley, et al., 2007), which could have been a contributing factor in the breakdown of the aggregate and the release of some clay minerals into the mix.

In August 2013 the NZTA released an additional clause to the Request for Tender (RFT) Maintenance Specification (NZ Transport Agency, 2013). This outlined further NZTA testing requirements for the PLQ basecourse. This was the result of pavement failures in a number of locations which required maintenance such as dig-outs, mill and fill, and rehabilitation. For the future use of PLQ aggregate, NZTA required a site-by-site approval, as well as additional testing, including PI and CI.

3.3.2 Aerial Photography

Aerial photography of the quarry was easy to access with the publication of Google Earth Images (Figure 3.1.). The progression of the quarry pit was observed from images dating back to 2002 until the last image in 2015, where the pit is RL-45 (45m below sea level). This indicated the expansion of the quarry both laterally and vertically, and can be correlated with the geological map (Riley Consultants 2008) discussed in section 4.3.3.

Figure 3.1 Left to Right Aerial image of Poplar lane Quarry a). taken on 01/12/2002, b). taken on 14/02/2007, c). taken on 15/06/2015 and d). taken on date 11/05/2016. All images extracted from Google Earth

3.3.3 Geological Map

Geological mapping was conducted by Riley Consultants Limited in 2008, and maps were produced (Figure 3.2 and 3.3).

The geological plan (Figure 3.2) identifies the units within the quarry and surrounding area. It confirms that the rock found within the quarry is andesite. It is displayed as three varying types of andesite; porphyritic andesite (A-p), vesicular andesite (A-v) and micro-veined andesite (A-mv). Riley Consultants (2008) describe the porphyritic andesite to be mostly brown to grey and moderately weathered, with some local areas of highly (moderately to completely) weathered rock. The vesicular andesite is described as brown to grey and predominantly moderately weathered, with vesicles up to 5mm, and moderately strong to strong. Areas of weakness adjacent to defects. The micro-veined andesite is generally brown-grey and moderately weathered, with micro–fractures less than 0.5mm wide. The majority of the quarry is comprised of the micro-veined andesite.

Figure 3.3 illustrates a cross section of the quarry indicating the geological units shown in figure 6 (Riley Consultants, 2008). It also displays the Rock Classification which overlies the engineering cross section (figure 3.3) to aid in identifying the quality of the rock. The classes listed in the legend are described in Table (Riley Consultants, 2008);

Table 3.1 Description of rock classification from geological map (Figure 3.3)

Class	Description
Class One	The highest quality rock which has the highest strength and least amount of weathering.
Class Two	Contains at least 50% of Class One with the remaining rock comprising lesser quality rock.
Class Three	This rock is more weathered and has a lower strength than Class One and Two.
Class Four	This rock is the most weathered with the lowest strength, and comprises pyroclastic material (ash, tuff or ignimbrite).

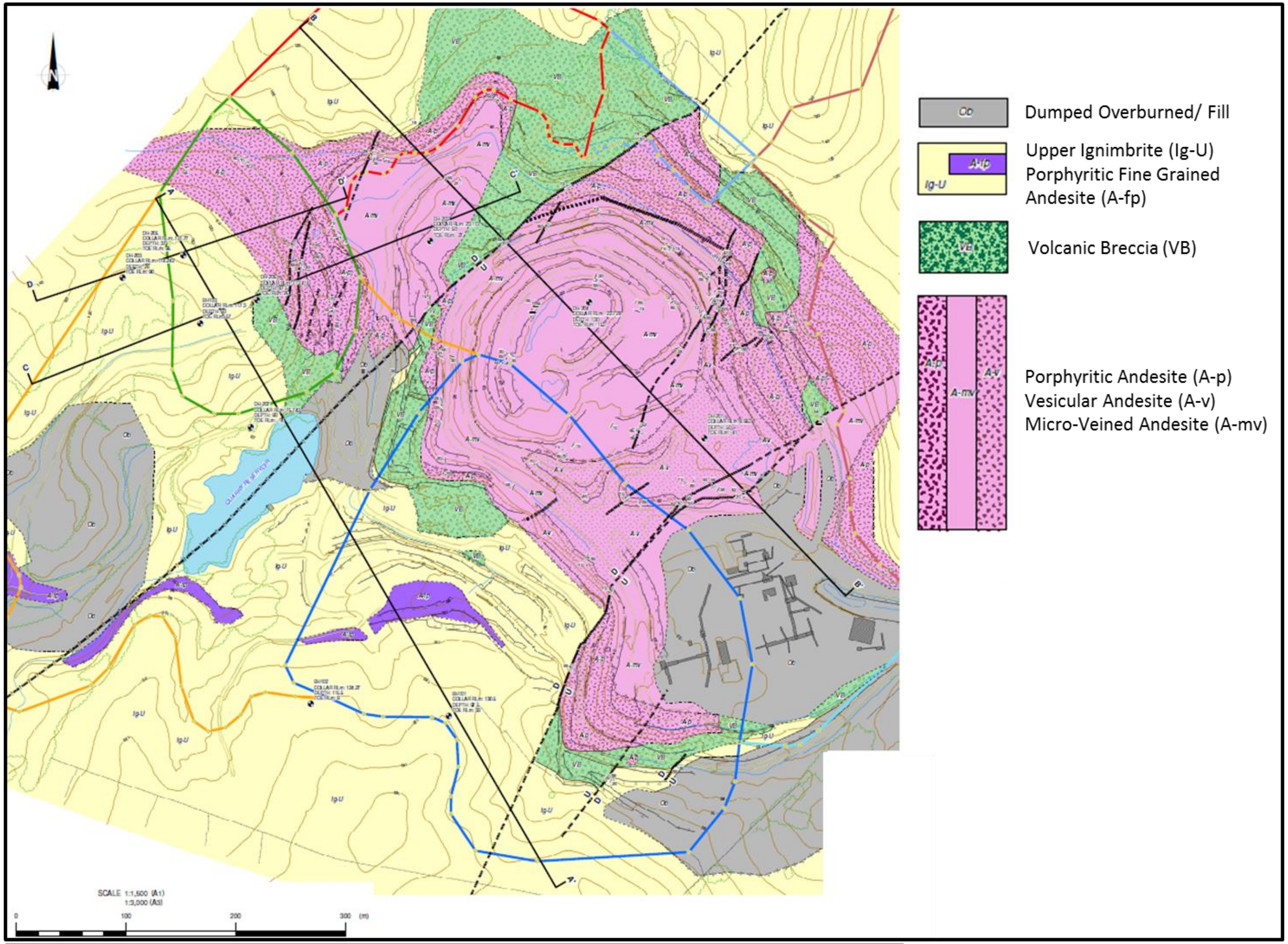

Figure 3.2 Geological plan of Polar Lane Quarry (Riley Consultants 2008). Note: only geological units are listed in the legend, symbol s not included.

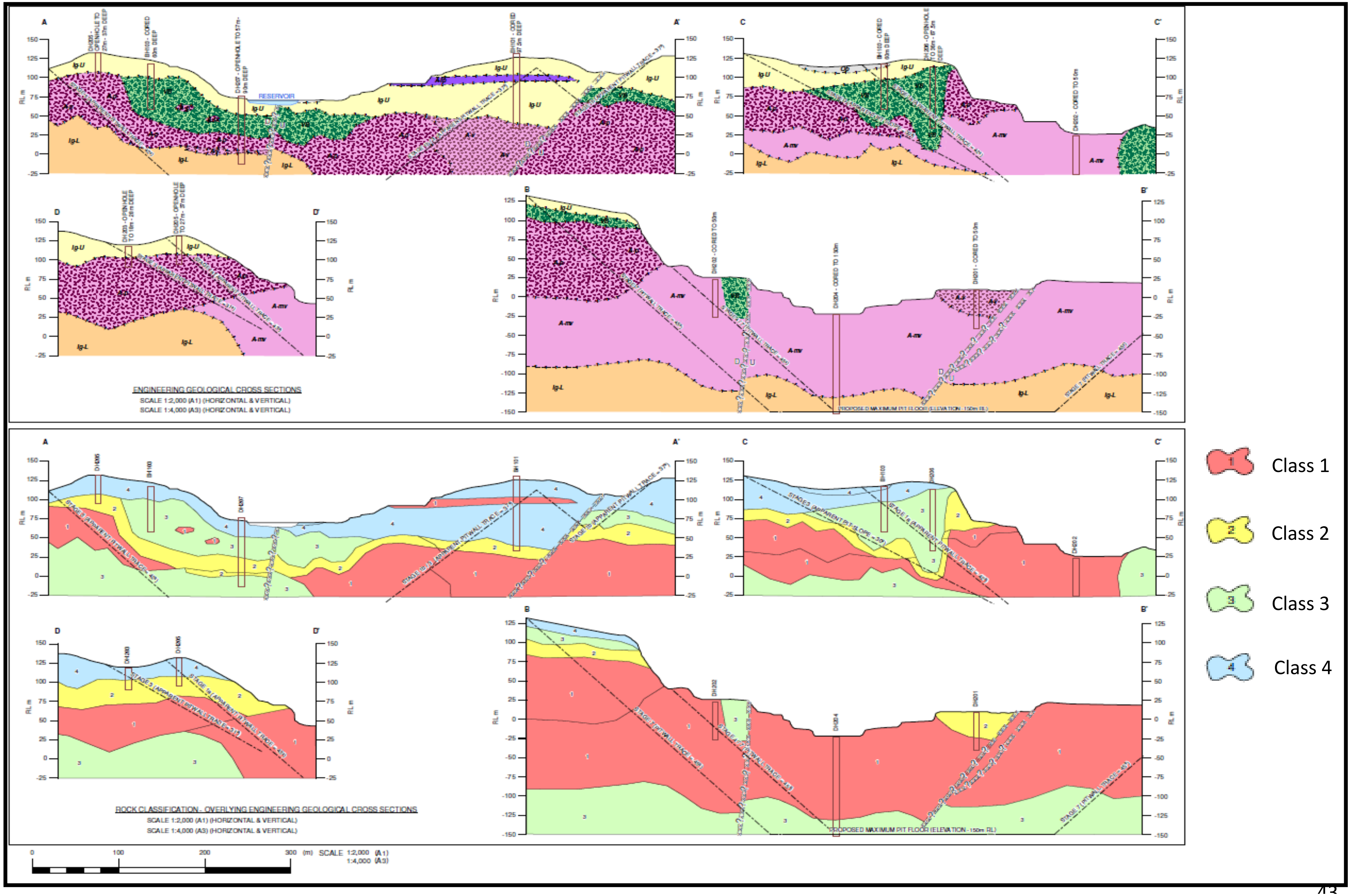

Figure 3.3 Geological cross section of Poplar Lane Quarry (legend derived from Figure 3.2). Rock Classification Cross Section categorise the rock into classes based on quality (Riley Consultants, 2008)

3.4 Field Investigation

3.4.1 Mapping Procedure

Mapping for this thesis study involved producing free-hand sketches, feature identification, images, sample collection and joint space mapping. This was to determine the variability of joint sets, fractures and weakness zones both vertically and horizontally at each site as well as within the quarry.

The mapping was completed shortly after blasting and removal of material to allow for accurate identification of the rock face when the exposure to the elements was minimal. Figure 3.4 indicates the location of the three sites where extraction of aggregate and mapping took place; each area was situated at a different elevation separated by a haul road.

The faces mapped correlate to the material tested, it appears that the material is known to vary considerably (Fulton & Topp, personal communication, 2015). Seams of a differing weathering grade would commonly fall within other grades, and selective processing was required. Due to safety reasons and the nature of the quarrying, the areas allocated for mapping for this research could only be the areas where access was granted. All the joint set data and other information collected from the three quarry sites can be found in Appendix G.

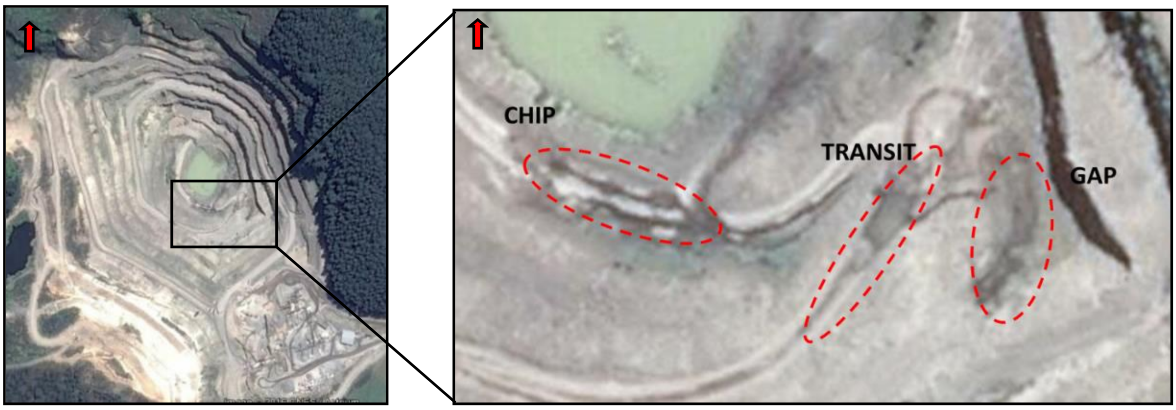

Figure 3.4 Aerial view of Polar Lane Quarry indicating where the three extraction/site areas were located. Image extracted from Google Earth on the 05/11/2015.

3.4.2 T-Grade Material

T-Grade material, typically extracted to produce Transit AP40 (NZTA M/4), ranges from moderately to highly weathered, dark blue-ish grey, massive porphyritic andesite and is strong to very strong with close to moderately spaced discontinuities. It has closed micro-veins and phenocrysts of plagioclase and orthopyroxene, the fractures and joints causing the material to be blocky up to 2m^2 Figures 3.5 and 3.6). Six hand samples were taken from across the face (as marked on the map – Figure 3.6) to be used for thin section analysis (Figure 3.7).

Figure 3.5 South East facing T-Grade site after material was hauled to the processing plant. Large blocky like material with smaller blocky material near larger fractures

The lineation and spacing of fractures and micro-veins can be seen in Figure 3.7. The spacing between fractures is 10mm. The micro veins look to extend over the width of the hand sample with sections of the vein opening less than 1mm wide, up to 20mm in length. They are detectable by the iron staining surrounding the vein. The largest phenocrysts of plagioclase are as large as 5mm, and are not intersected by the veins, indicating that the minerals and vein inclusion occurred around the same time of formation.

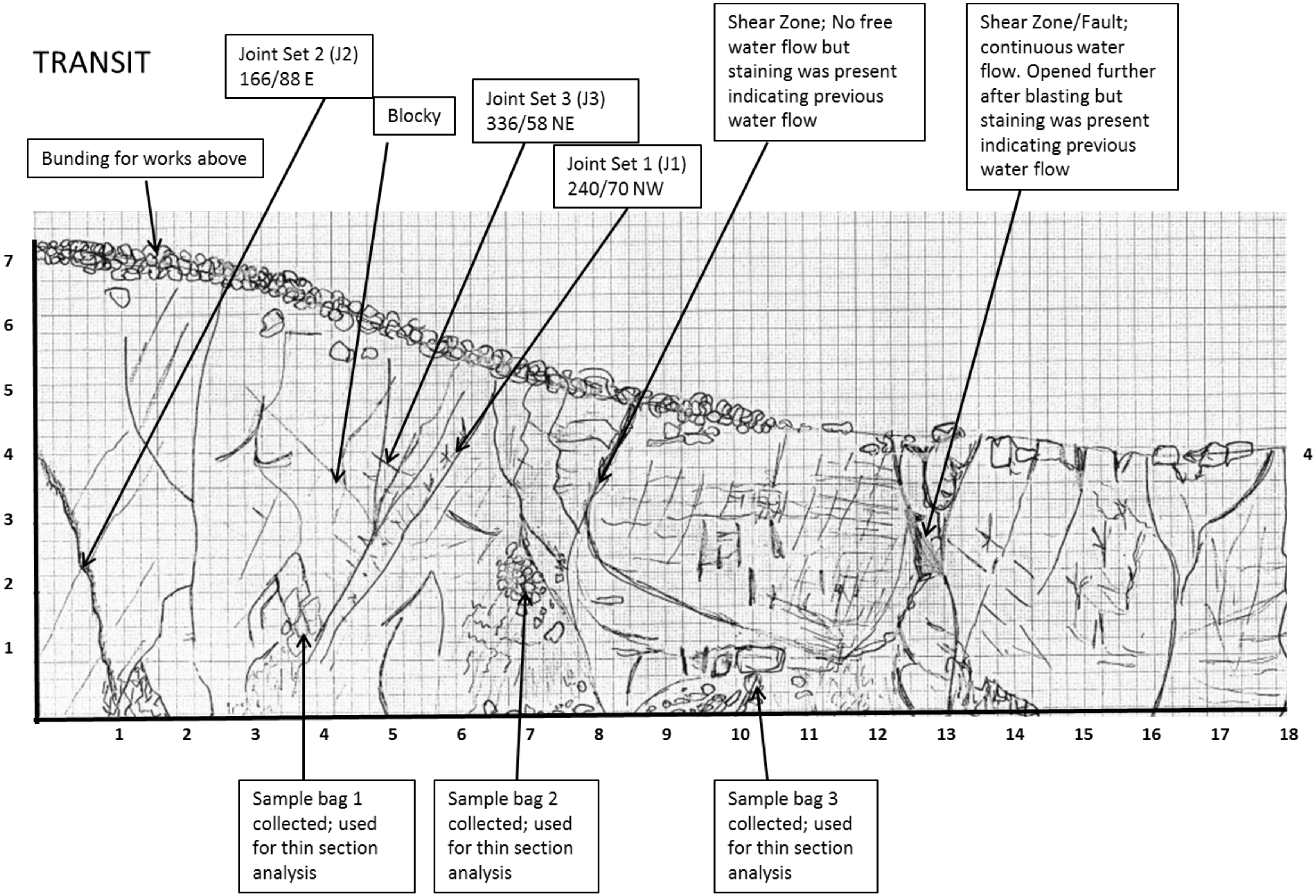

Figure 3.6 Hand drawn sketch of T-Grade face after blasting and extraction

Figure 3.7 T-Grade material hand sample, note the lineation of veins and micro fractures. Large minerals are phenocrysts of k-feldspar, plagioclase feldspars and pyroxenes

3.4.3 C-Grade Material

C-Grade is the least weathered rock, typically used for the production of chip material, ranging from slightly to moderately weathered dark bluish grey, massive porphyritic andesite, and is strong to very strong with close to moderately wide to very widely spaced discontinuities. It has closed micro veins and phenocrysts of plagioclase and orthopyroxene, the fractures and joints causing the material to be blocky up to 8m^3 (Figures 3.8 and 3.10). Six samples were taken across the face, which is marked on the mapping sheet, and processed for thin section analysis.

The hand sample shows few open fractures with evidence of large sized phenocrysts of plagioclase up to 5mm. Fractures, 1mm wide, are visible throughout the sample and the orientation is consistent across the face of the sample. The fractures are approximately 5-10mm apart. Iron staining is visible in the hand sample which is orientated perpendicular to the lineated fractures (Figure 13).

Figure 3.8 South West facing C-Grade site after material was hauled to the processing plant. Yellow lines indicate 5m intervals along the face used for mapping purposes.

Figure 3.9 C-Grade material hand sample. Slight lineation of veins and micro fractures. Large crystals are phenocrysts of potassium feldspar, plagioclase feldspars and pyroxenes. Note the iron staining across the bottom of the sample which does not follow an obvious micro-fracture

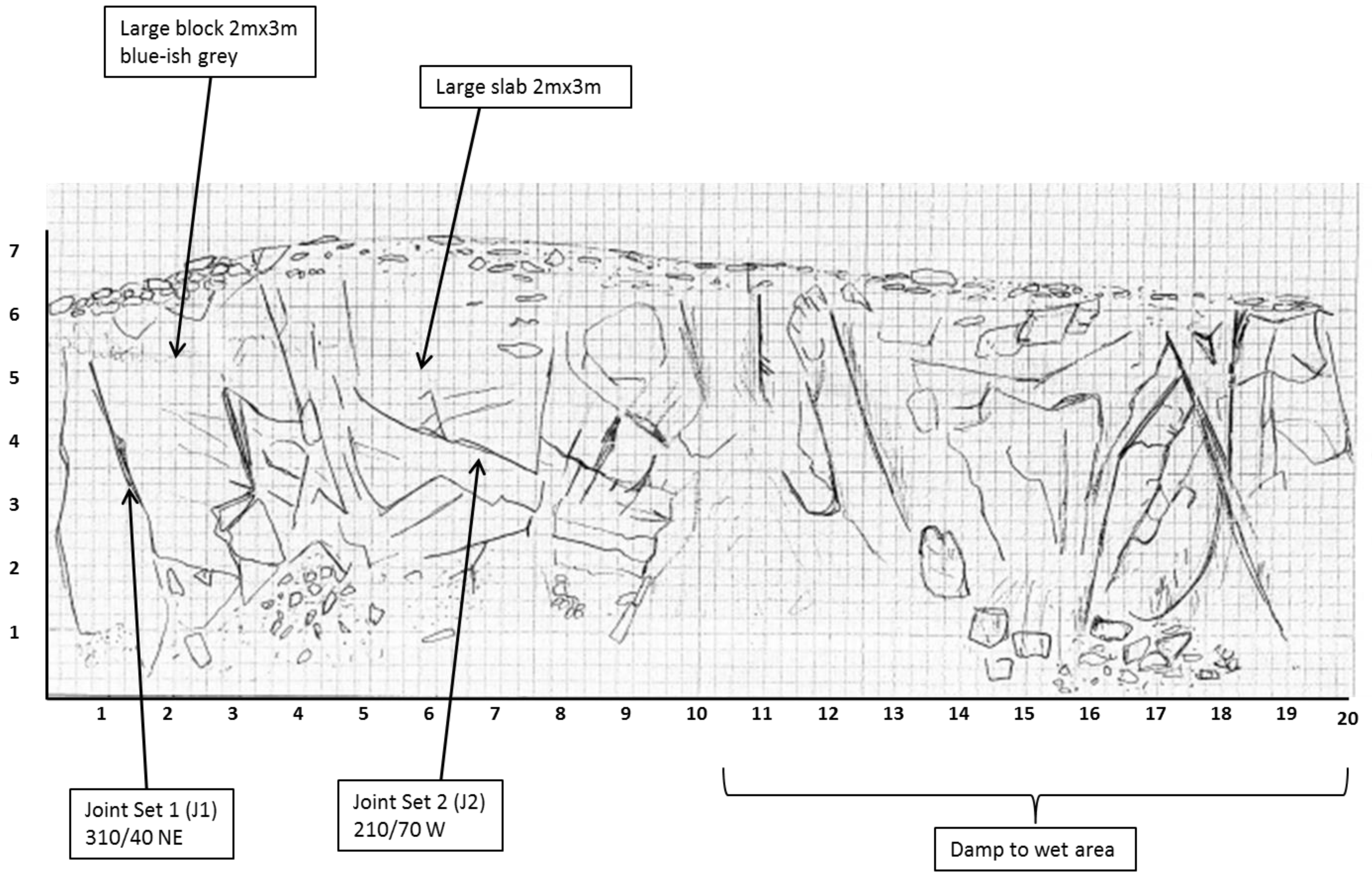

Figure 3.10 Hand drawn sketch of C-Grade face after blasted material had been extracted

3.4.4 G-Grade Material

G-Grade is the most weathered rock, ranging from highly weathered to completely weathered, dark bluish grey to reddish brown, massive porphyritic andesite. It is weak to strong with close to very closely spaced discontinuities. It has micro-veins that are in-filled with yellow silty clay fines, and the fractures and joints cause the material to be blocky (Figures 3.11 and 3.14). Quarry operators use the colour of the rock as a weathering indicator. Six hand samples were taken across the faces, marked on the mapping sheet as sample bag collection area (Figure 3.14), and subjected to thin section analysis. The micro-veins, 5 mm wide and with up to 50mm persistence, were found extensively throughout the G-Grade material (Figure 3.12 and 3.13).

Figure 3.11 East facing G-Grade site after material was hauled to processing plant. Highly fracture material with loose rubbly material throughout.

The hand sample is a reddish brown colour, with phenocrysts of plagioclase up to 3mm and no obvious orientation (Figure 3.12). There are open fractures up to 3mm wide in some places, which pinch and swell along the fracture line. A yellowish silty clay in-filling is visible in some of the fractures. A larger sample found at the site shows open fractures of 20mm in length and up to 5mm wide; these too have a yellow silty clay in-filling material and show a strong lineation within the rock.

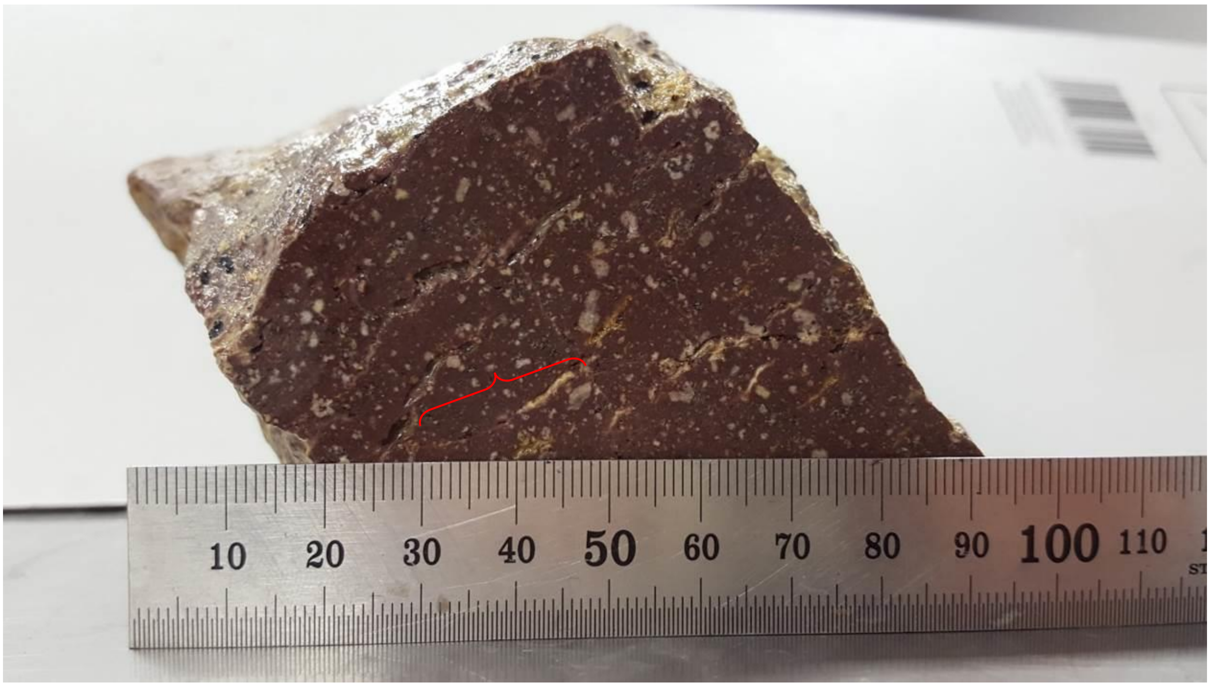

Figure 3.12 G-Grade material hand sample. Slight lineation of veins and micro fractures. Large minerals a re phenocrysts of potassium feldspar, plagioclase feldspars and pyroxenes. Note the pinching and swelling of micro-veins indicated by the red brace, some contain in-filing material evident by the yellow staining.

Figure 3.13 G-Grade material with micro-veins. Note the persistence and width with obvious in-filling of silty clay fines. Rock hammer used to show scale

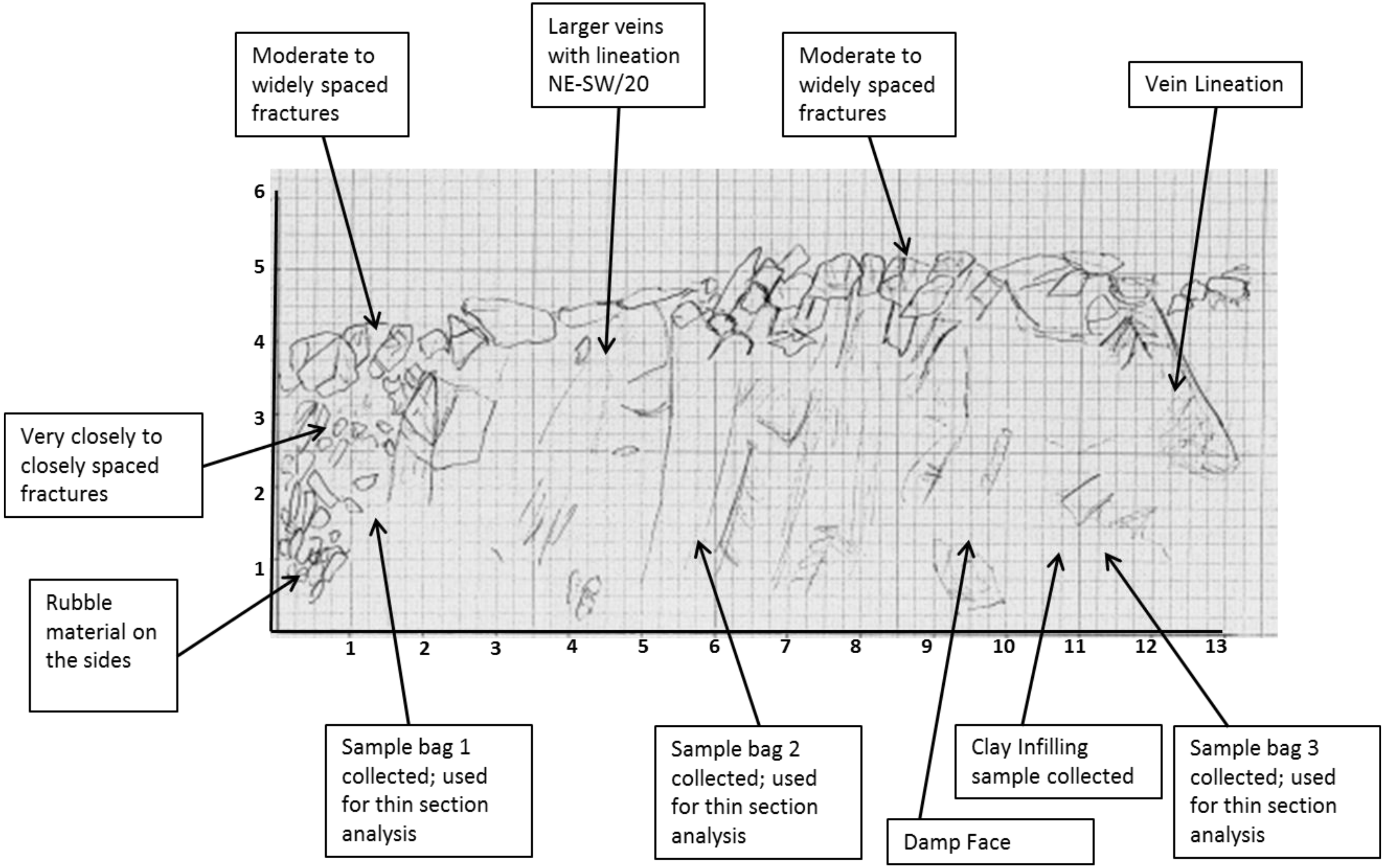

Figure 3.14 Hand drawn sketch of G-Grade face after blasted material had been extracted

3.4.5 Sampling of Aggregate

The three grades of aggregate material were processed through the primary and secondary crushing plant using the Transit settings i.e. the C-Grade, T-Grade and G-Grade aggregate would be processed to produce AP40 at the same settings. It was decided that no Barmac fines would be included in the material produced, in order to establish base results for comparison. Barmac fines are traditionally included into the Transit AP40 material to increase the fines content so that it meets the TNZ M/4 (2006) specification. At the time of mapping, there were no areas of completely weathered material being extracted, and so the G-Grade material quality may be of a higher standard, similar to that of the T-Grade material.

Each sample pile, derived from a 200 tonne graded material pile, had two external pads produced from them for sampling. Material was mixed by a loader, then removed from the stockpile to make the pad; i.e. the pad was not made on the stock pile. The loader driver was trained and competent in the IANZ 4407:1991 sampling method 2.4.6.2.2 *machine method of sampling stockpiles of well graded aggregate*. The method chosen was a modified method to accommodate the large number of samples being collected.

As per the research plan, six samples of 120 kg each were collected from the two external pads. The research plan can be found in Appendix F. Due to the safety requirements for lifting, the sample was bagged in six separate bags of 20-25kg each. A seventh sample was collected for additional testing in Christchurch, if required. Four samples were collected from the larger pad and three from the smaller. Each shovelful was taken from a random place on the pad so that each individual bag was representative of the pad and aggregate. Testing was allocated to the various laboratories as follows;

Fulton Hogan PLQ laboratory

- Particle size distribution
- Moisture content
- Sand equivalent
- Weathering resistance – preparation

Fulton Hogan Canterbury laboratory

- Clay index
- Plasticity index
- Weathering resistance
- California bearing ratio
- Crushing resistance, including ethylene glycol test
- Indirect tensile strength
- Broken faces
- Additional testing

University of Canterbury

- XRD analysis
- Petrographic analysis
- Scanning electron microscope (SEM)

The results from the tests performed on the samples collected are presented and discussed in Chapters 5 and 6 respectively.

3.4.6 Crushing and Process Review

A number of complex factors go into managing a quarry. The selection process for the material is important, especially at PLQ where the vertical and horizontal variability is extensive. Before blasting takes place, an indication of the material classification is determined from data derived from the geological mapping by Riley (2008), as shown in figures 3.15 and 3.16. Other factors to be considered include the material of the faces above and below where blasting is to take place. Previous blast profiles are also considered. Another indication of the rock type is how the material releases. Harder rock, which is less weathered and less fractured, releases more effectively than the softer more weathered rock, as the softer rock absorbs the force of the blast. These indicators only give a 60% confidence level, based on the quarry manager's experience, on the weathering grade and subsequent material classification. The final confirmation, is completed as it is processed through the primary and secondary crushing plant (Figure 3.16).

Before the blasting occurs, the site is cleared and levelled. Grid patterns are designed specifically for each site; holes 89 mm in diameter (115mm or 102mm holes were drilled in the past) are drilled into the surface, in which explosives are impregnated. The mass of explosive used varies on the size of the site and ranges from approximately 400kg to 8000kg.

Blasting data has been recorded since March 2001, and blasting is conducted on average twice a month. The average calculated volume (from 2001 -2015) of material obtained per blast is 6300m^3. The largest volume from a blast was calculated at 17 181m^3 in February 2004. The powder factor is a useful indicator of how successful a blast is, being a relationship between the amount of explosives used and the amount of broken rock accumulated after blasting. A high powder factor indicates a harder rock, and typically ranges between 0.6 and 0.8 at PLQ. Secondary blasting to break down the rock further (if the initial blast was insufficient) is conducted once or twice a year. It is not a common process as the quarry is extensively fractured and faulted so the blasts are generally adequate in capturing all the material allocated for that blast.

The blasting data recorded only identifies the blast site and bench number, which then correlates with the pit map (figure 3.15). This information is only recorded for blasting purposes, and unfortunately cannot be accurately located on that map, therefore no parallels could be drawn to test results and locations (both vertically and laterally) within the quarry.

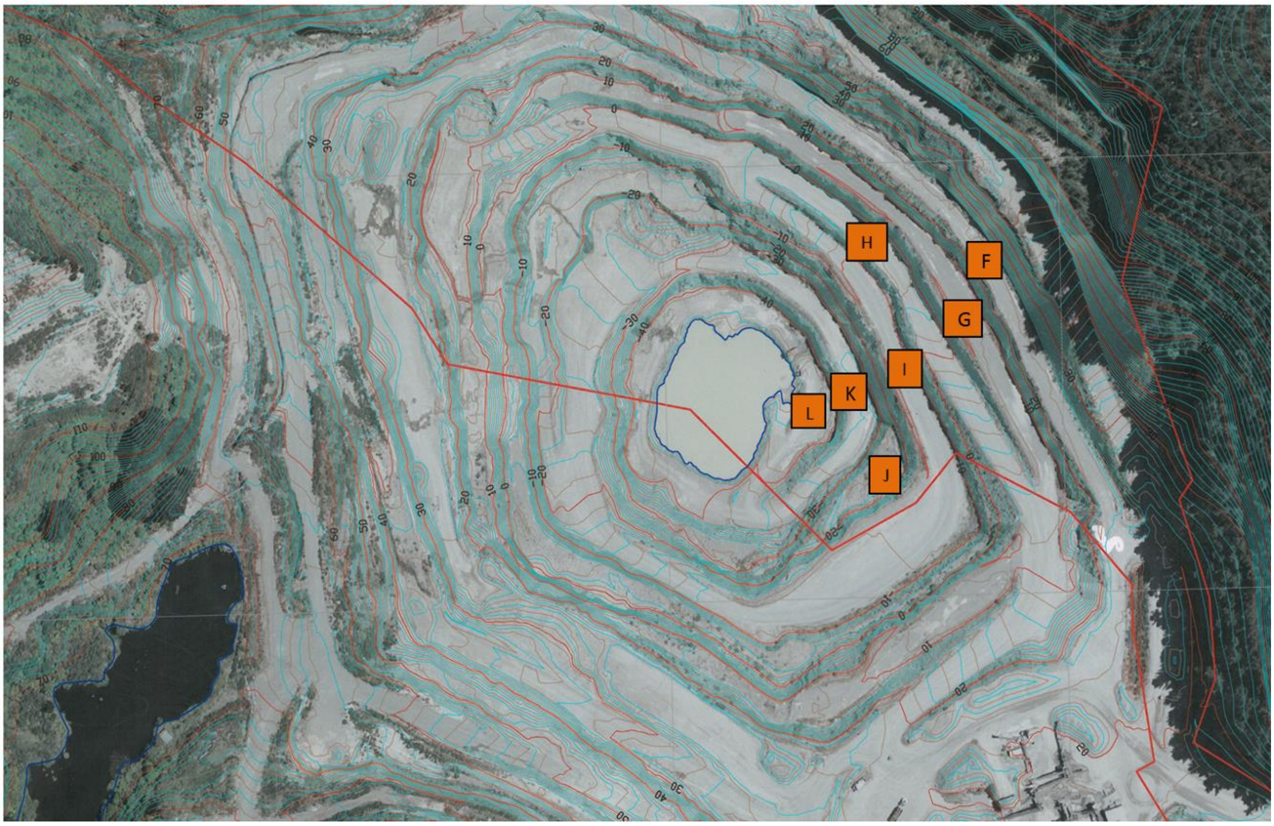

Figure 3.15 Quarry pit map, letters in orange indicate bench identification

After blasting, the material is hauled to the processing plant. It is stockpiled in the three separate classifications (Transit, Chip and GAP) before being passed through the primary plant (figure 3.16). The primary plant crushes all the material through a jaw crusher which was set at approximately 100mm. This material is then stored on a surge pile and transferred to the appropriate secondary plant for further crushing

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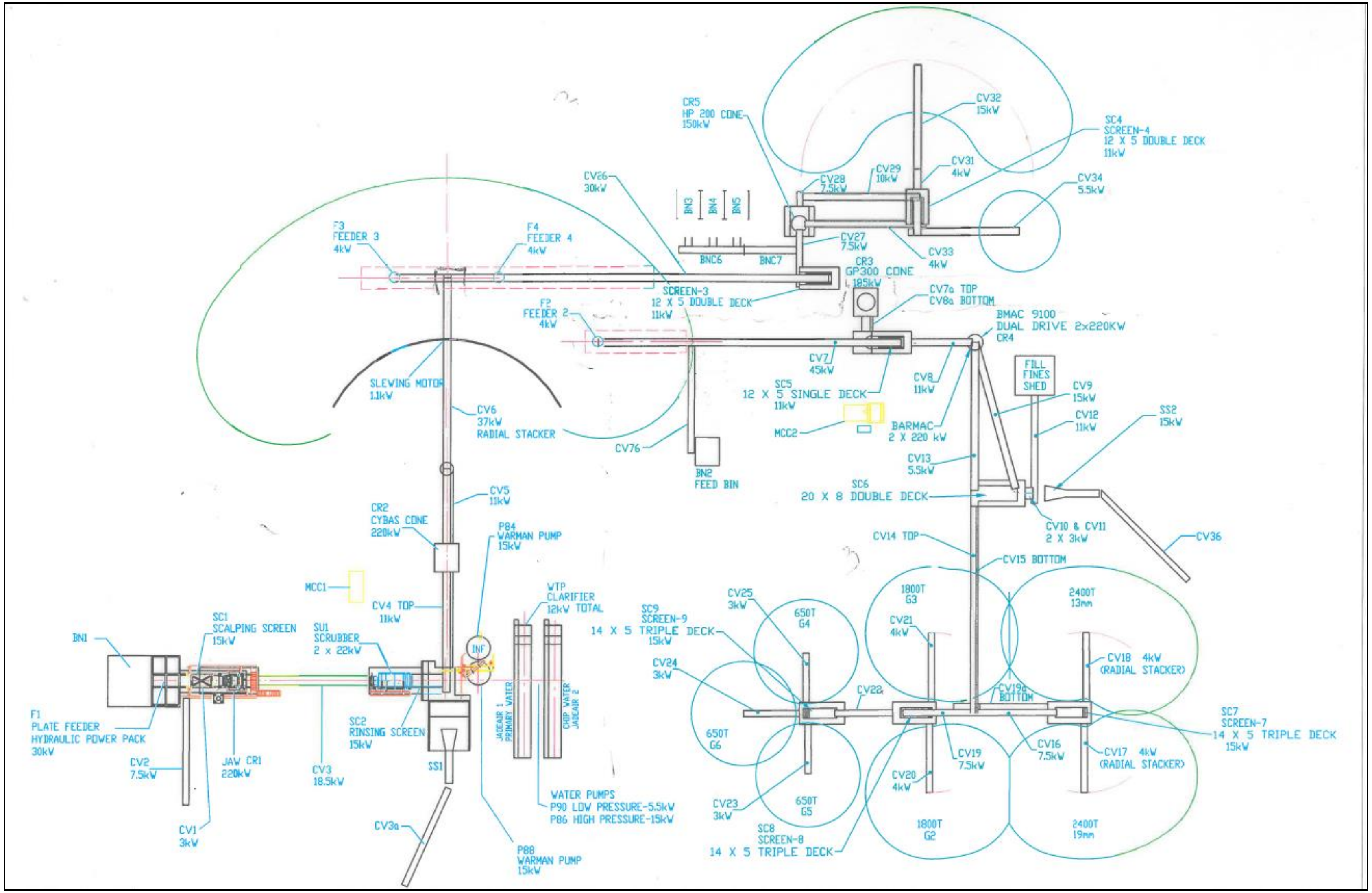

Figure 3.16 Crushing plant schematic including primary and secondary plants.

The Transit plant passes the material through a cone crusher set at 24mm and then over a screen of 43.1 aperture. Aperture details the size of the sieve spacings, therefore the spacing on the screen would be 43.1mm wide diagonally. This allows for an accurate production of Transit AP40. Testing of the material is conducted at the start of every run, generally between 400 and 500 tonne. Chip and GAP rock are passed through alternative plants with different settings to produce the required product.

The source material from which the samples were derived was crushed first through the Primary plant, which is actioned by a jaw crusher which was set at approximately 100mm. The resulting material was stored on a surge pile and then transferred to the appropriate secondary plant for further crushing. Six hand samples (two from each weathering grade) were taken from each surge pile, these were used for hand sample and petrological analysis.

For this research, all the material was passed through the Transit secondary plant irrespective of its weathering grade. The transit plant passes all aggregate through one cone crusher set at a closed size of 24mm and a screen with a 43.1 aperture. Approximately 200 tonnes of each grade was processed and piled, ready for sampling at part of the study.

3.5 Discussion and Synthesis

Chapter 3 detailed the field investigation conducted for this part of the research. It included a thorough review of historic data from PLQ. Aerial photography and mapping were included to provide a greater understanding of the engineering geology of the quarry, and the progress of the production process over the years.

A detailed mapping and geological investigation was completed on the three quarried faces which included hand drawn sketches, photographs and comprehensive joint mapping. This gave an indication as to the type and quality of material extracted from that area. The G-Grade material was considerably more jointed and showed large micro-veins and open fractures with in-filling material, whereas the C-Grade face had larger blocky material with minimal open fractures and was less jointed.

The crushing and processing plant was reviewed, and a detailed description of the process was outlined. The nature of the quarry necessitates the use of blasting and crushing to provide the basecourse material. There was limited data available that accurately identified where the material was sourced from in the quarry. This information is relevant and important for the ongoing analysis of the quarry.

4. Chapter Four: M/4 Specifications

4.1 Introduction

This chapter presents, illustrates and discusses the data derived from three data sets. The first being the historical records of test reports relating to PLQ TNZ- M/4 AP40 aggregate that is typically produced from T-Grade material. The second data set comprises results of laboratory testing of the PLQ AP40 aggregate samples collected for this research, and tested according to the TNZ M/4 specification. The third data set contains results from the draft NZTA M/4 specification.

The historic reports of the results from both source and production property testing for the Transit M/4 AP40 material were collated from 2003 to 2015, which was tested either at the B.O.P Fulton Hogan laboratory or by a contracted laboratory during these years. The number of samples collected and tested differed each year, which can be attributed to the increasing focus on quality and the quantity of aggregate produced each year. As can be expected, the failure of a material sample to meet the required standard meant the test was likely repeated. This explains why some years have many more test reports than other years. A detailed inventory of results for the historic data set can be found in Appendix H. It was important to conduct this analysis to identify any historic changes or trends within the material and align these with operational, production and performance concerns and changes.

The samples collected for testing for this research were from the three differing weathering grades, termed C-Grade, T-Grade, and G-Grade. These grades were tested independently to determine if any correlations and comparisons could be drawn. All of the three weathering grades were processed and sampled in the same manner, as detailed in Chapter Three. All test reports, a detailed inventory of results and result from the control stone, can be found in Appendix I. Six tests on each of three weathering grades of material (C-Grade, T-Grade, and G-Grade) were planned, for a total of 18 data sets. The sample size was selected to ensure statistical validity. The plan of six tests per grade was not always achieved due to insufficient sample collected, equipment failure, or time constraints. A greywacke control stone was used as a validation measure; this was sourced from Miners Rd Quarry, and only TNZ M/4 AP40 was tested. The results, with that of the control stone, are graphed together with the results from this research.

Only those tests where amendments or additions have occurred in the draft NZTA M/4 specification are illustrated and detailed here. This includes analysis of data from both the historic data set and the results obtained from testing for this research (T-Grade, C-Grade and G-Grade).

All source property results from the historical data and M/4 specification testing was compiled for Crushing Resistance, Weathering Quality Index and California Bearing Ratio tests.

No amendments to the Source Property tests were included into the draft NZTA M/4 specification. Therefore no data need be repeated in this section.

This section includes the collection and collation of the historic data for TNZ M/4 product from 2003 to 2015, and also details the results of the tests specified in the TNZ M/4 and the draft NZTA M/4 conducted on the material collected for this research. This includes results for the Sand Equivalent, Plasticity Index, Clay Index, Particle Size Distribution and the Broken Faces content. The additional tests included in the draft M/4 specification are the Sand Grading Exponent, Weighted Clay Index, Weighted Plasticity Index and Grading Slope Control. In summary, based on the yearly average the Sand Equivalent has consistently met the specification and rarely did samples not meet this standard. The Clay Index test was consistent in not meeting the specification for both the historic results and those collected for this research. The Plasticity Index has showed a large range of variability in the past 13 years with some results having no plasticity and others having a relatively larger plasticity index. The PI for the samples collected for this research were all non-plastic. All samples had 100% broken faces. The PSD varies over the years but has met the specification consistency in the past. This section details these results.

The amendments and changes have been discussed and illustrated with data from both the historic test results and the results of data obtained for this research. This includes the Weighted Clay Index, Weighted Plasticity Index, Sand Grading Exponent and Grading Slope Control

4.2 Crushing Resistance

The test for Crushing Resistance was conducted in accordance with the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*. The specification requires the proportion of fines passing the 2.36mm sieve to be less than 10% after a load of 130kN is applied to the sample over ten minutes. The lower the percentage of fines generated indicates that the aggregate did not break down abnormally, which implies that it will withstand loading from traffic when in service.

The PLQ basecourse consistently met this standard over the 13 year period (2003-2015), and the average for each year is displayed in Figure 4.1. The maximum and minimum results were 7% recorded in 2004 and 2.9% recorded in 2003. The 2.9% minimum was also the lowest percentage recorded for an individual sample. The maximum value for an individual sample was 9.3%, recorded in October 2004.

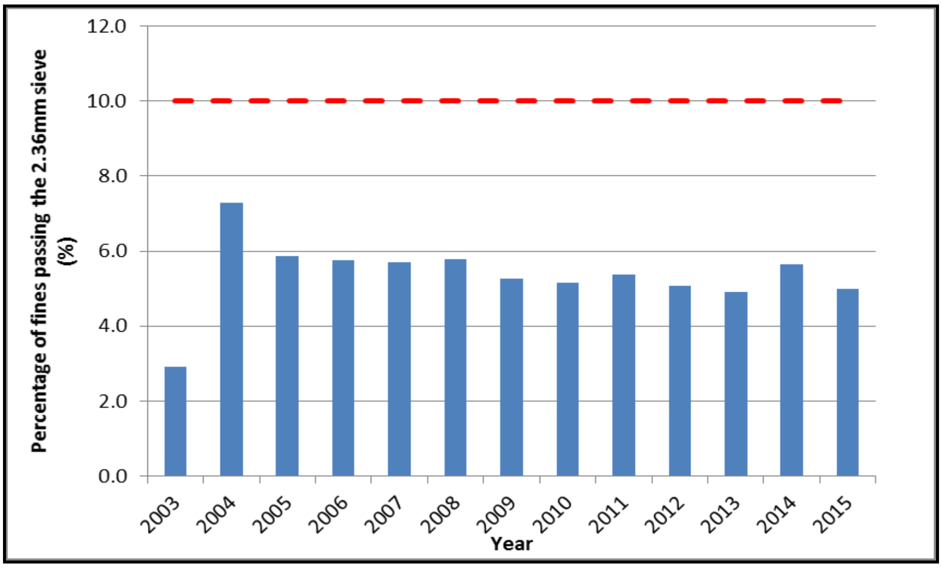

Figure 4.1. Average Crushing Resistance for Transit AP40 material tested each year from 2003 to2015. Red dashed line indicates the maximum allowable percentage passing the 2.36mm sieve for compliance with specifications.

Figure 4.2 displays the variation in results between individual samples, and between the differing weathering grades for the samples collected for this research tested according to the current M/4 specification.

Fourteen samples were tested for crushing resistance. The lowest value recorded was 2.9% and the highest 4.4%, which is still low considering the maximum value allowed is 10%. C-Grade material had the lowest average with 3.3%, and the highest was the G-Grade material with 4.1% (T-Grade material average was 3.4%). This was in accordance with what was expected, with the less weathered material (C-Grade) performing the best, although the results between the three grades were very similar. The control stone had lower fines generated indicating its high strength when subjected to traffic loading.

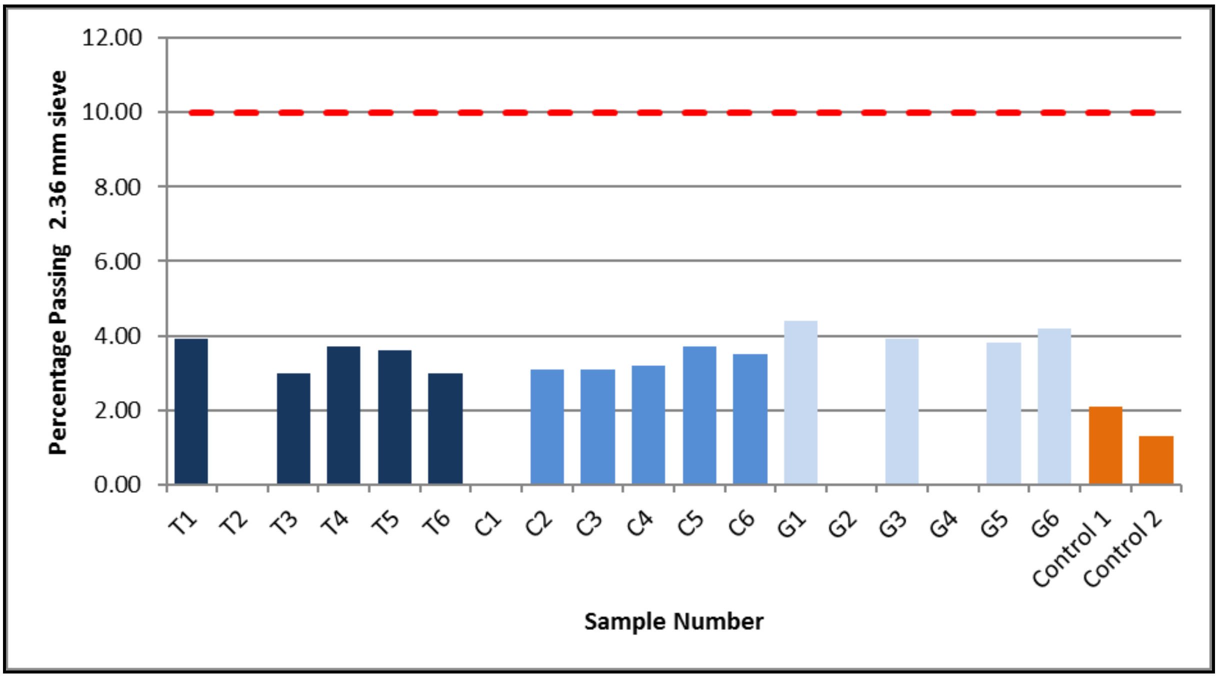

Figure 4.2 Crushing Resistance for T-Grade, C-Grade, G-Grade and Control sample basecourse aggregate. T = T-Grade C = C-Grade, G =G-Grade. Dashed red line indicated the maximum allowable percentage for compliance with the current TNZ M/4 standard

Figure 4.3 shows the statistical representation of all results from 2003 until the end of 2015, including the results from material tested for this study. It does not include results from the control stone. It can be determined that there is general trend of increased crushing resistance in the period, as well as between the years, and that the research samples showed little variance between their results. This can be attributed to the relatively close proximity of each research site within the quarry, whereas the variance within each year is likely due to different areas of the quarries being processed. The result of 2003 is only shown as a single line as there was only one test conducted and therefore not enough data to conduct a statistical analysis. Small variances such as in 2011 could indicate where samples were processed from adjacent faces, either on the same bench or above and below. The location of blast sites are only available from 2013 onwards; these records would indicate where the material was processed from in a given year. The T-Grade, C-Grade and G-Grade samples had considerably lower results than the yearly averages indicating an increase in crushing resistance and ultimately strength. The three sample grades aren't classed as outliers, as the variability between samples within each grade as well as the variability between each grade was minimal when compared to 2005 and 2014.

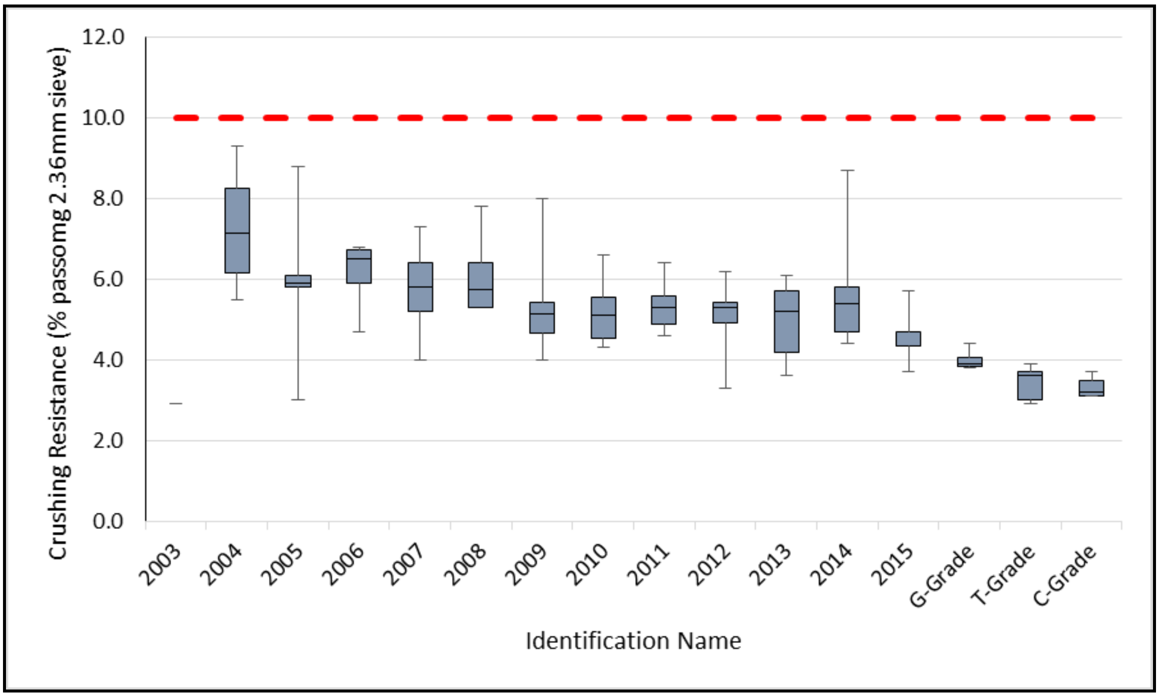

Figure 4.3 Crushing Resistance Box Plot for all historic test reports and the results from the three weathering grades. The dashed line indicates the limit for this test which is 10%

4.3 Weathering Quality Index

The material was tested for the Weathering Quality Index in accordance with the NZS 4407:1991 Test 3.11 *Weathering Quality Index Test.* The values from tests conducted from 2003 to 2015 (123 samples) are shown in Figure 4.4. The values range through a number of categories, but most of the results fall within the specified categories of indices AA, AB, AC, BA, BB or CA and are compliant. Eleven of the results, which equate to 9% of all the samples, failed to comply with this test specification. This could be due to variability in the quarry where the weather profile had increased and resulted in a sample that failed. The majority of these failures occurred in 2008, 2013 and 2014. Many of the samples returned the same result which explains why the graph appears to display only a selection of results, as the points overlap (Figure 4.4). More than half of the 123 test results were in the BB grouping (54%).

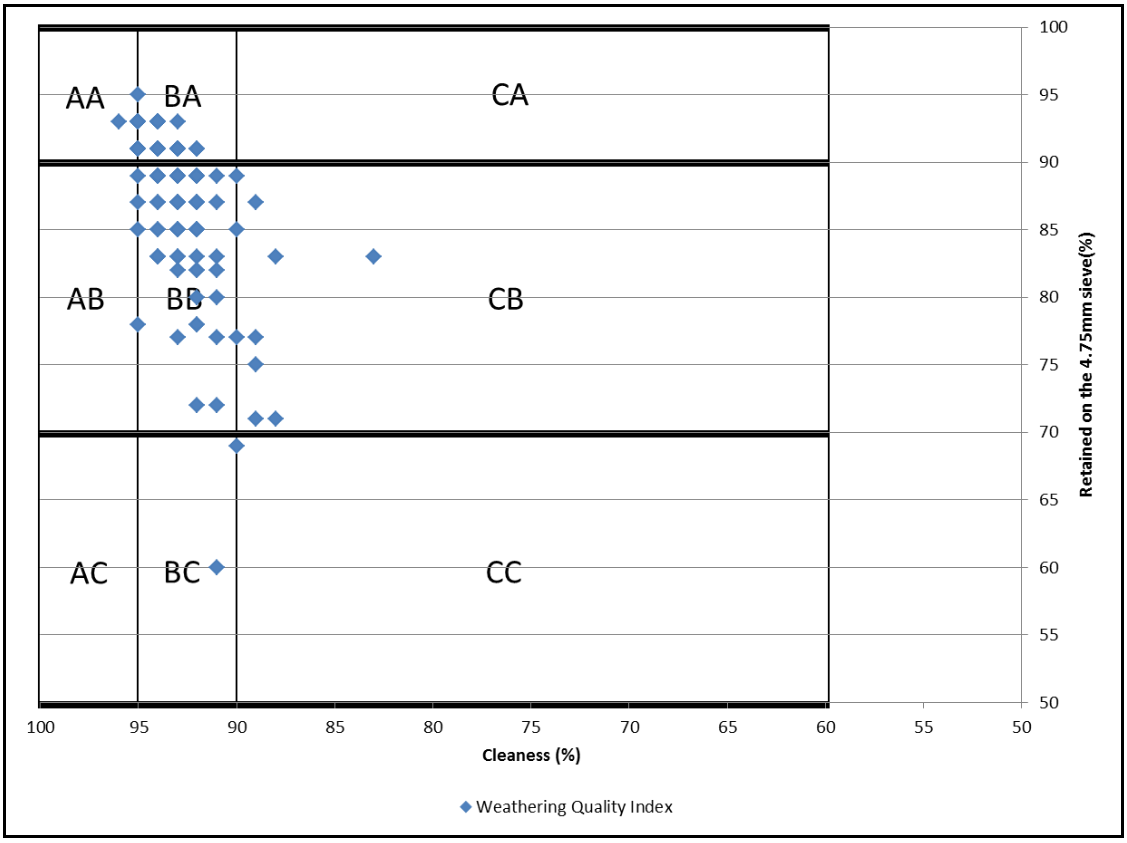

Figure 4.4 Weathering Quality Index for all samples of Transit AP40 material tested between 2003 and 2015. The specification requires samples to fall within the AA, AB, AC, BA, BB or CA categories for compliance.

The Weathering Quality Index (WQI) test for this study was conducted on all three weathering grades of aggregate (T-Grade, C-Grade and G-Grade), with a total of six tests for each grade. All 18 samples complied with the specification, which requires the sample to lie within one of the following categories of AA, AB, AC, BA, BB or CA (Figure 4.5). WQI values for all samples tested are displayed in the figure, but some samples returned the same values (overlapping points), creating only one data point. Where a result fell on a category line the sampled was placed into the lower category. For example, sample T1 returned a cleanness value of 95% and retention on the 4.75mm sieve at 95% and as the percentage retained on the 4.75mm sieve falls on the boundary between AA and BA, the sample is classed as BA. The highest ranking sample was C-Grade 3 (C3) which resulted in a WQI in the AA category. AA indicates a sample that is the least susceptible to weathering and the most desirable for road construction.

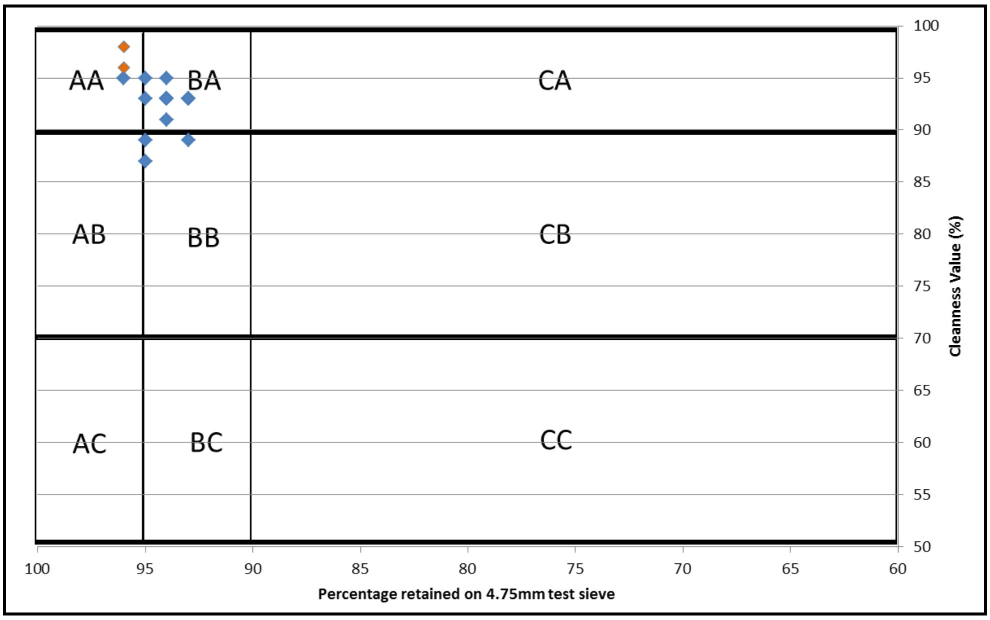

Figure 4.5 Weathering Quality Index indicated in blue for the T-Grade, C-Grade, G-Grade and the greywacke Control sample basecourse aggregate indicated by orange markers. T = T-Grade C = C-Grade, G =G-Grade. Data points for some samples overlap

The individual results for each weathering grade can be found in Figures 4.6 to 4.8. The C-Grade material performed the best (Figure 4.7) with all of its samples falling within the top two weathering grades (AA, BA). The other grades (T-Grade and G-Grade) performed well, with all samples performing similarly, and comply with the current TNZ M/4 specification (Figures 4.6 and 4.8).

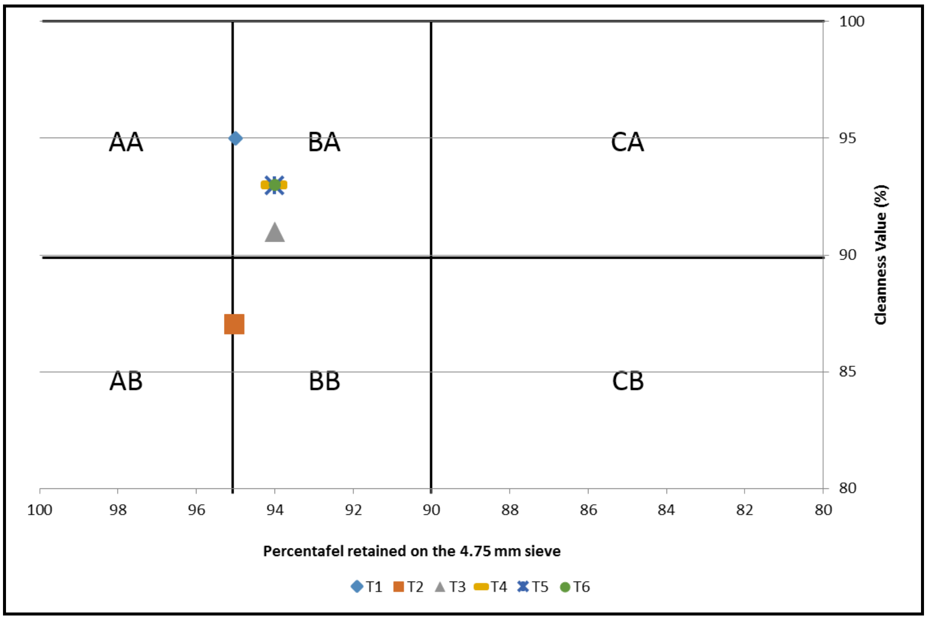

Figure 4.6 Weathering Quality Index for individual samples from the T-Grade material

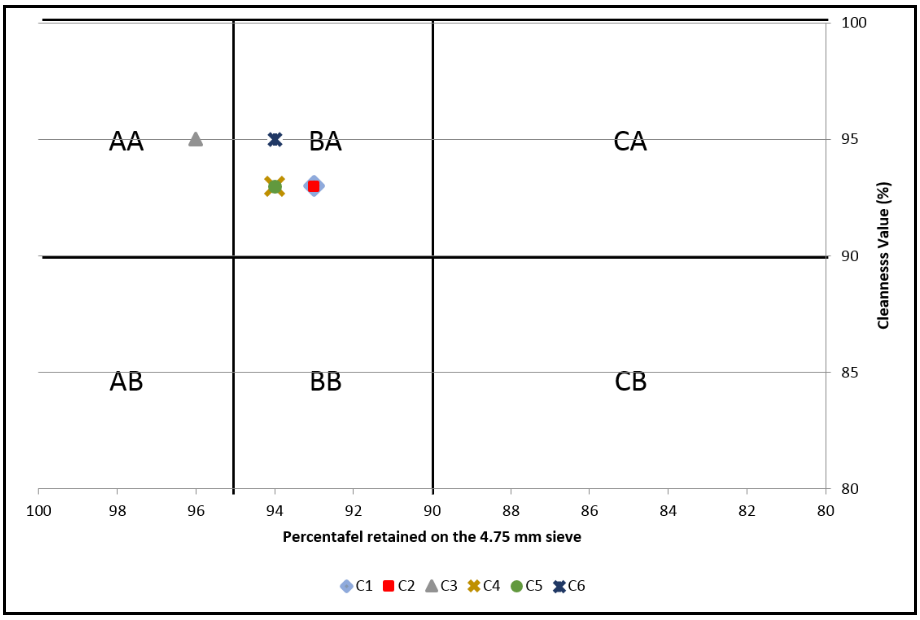

Figure 4.7 Weathering Quality Index for individual samples from the C-Grade material.

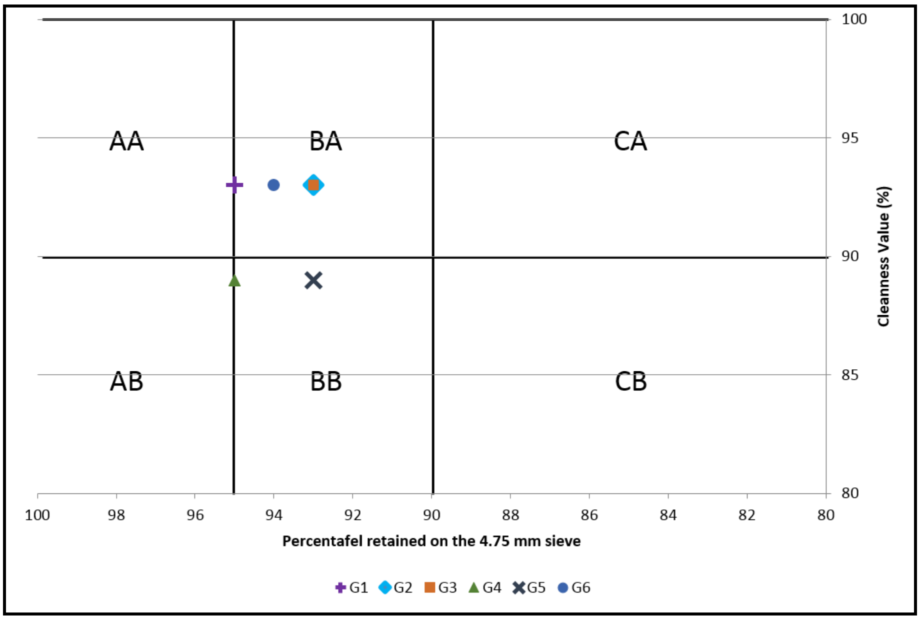

Figure 4.8 Weathering Quality Index for individual samples from the G-Grade material.

The material consistently passes WQI test with only a few samples failing in the past, so it is of no concern as it meets the parameters set in the M/4, indicating that when subjected to a number of harsh conditions the aggregates does not breakdown. The C-Grade material which is the least weathered, generally had best results, and there was no significant differences between the T-Grade and G-Grade samples. The WQI is a function of two factors, the cleanness result and the percentage retained on the sieve. It can be expected that the samples which failed, identified in the historic reports, can be attributed to the more weathered materials. By looking at the WQI 2008 sample which failed, it coincides with the same samples that produced high CI values around the same time. However, no assumptions can be drawn from this correlation because in 2012 the highest CI value was recorded, and the WQI for that sample was BB and did not fail. Similarly in 2013 many of the WQI samples failed, as did the CI, but they occurred at different times within that year so no conclusions could be made. No other correlations were drawn between the WQI and other tests performed.

4.4 California Bearing Ratio (CBR)

Material samples tested for California Bearing Ratio were compacted in accordance with NZS 4402: 1986, Test 4.1.3 *New Zealand Vibrating Hammer Compaction Test at Optimum Water Content* and tested for compliance according to NZS 4407: 1991, Test 3.15 *the California Bearing Ratio Test.* It measures the mechanical strength of a material using a penetration rod. The average CBR over the 13 year period studied well exceeds the minimum requirement of 80% (Figure 4.9), although in 2004 no CBR tests were performed. The lowest recorded CBR was 155% in early 2011, and the highest was 380% in June 2003. Surcharges are weights applied to the specimen to replicate the loading of material placed above that layer The subbase is usually the layer directly below the basecourse, so when testing the subbase, the volume of basecourse on top of the subbase would induce a load. Common practice does allow for the use of surcharges when testing basecourse, even though it is not specified in the test procedure for basecourse. Basecourse TNZ M/4 AP40 material is the final lift, in most cases, of a pavement before sealing. This should require no surcharge to be added to the sample before testing as there would be no layer above the basecourse to impose a load. Therefore as no layer is applied above the basecourse no surcharge should be applied during testing. In PLQ historic testing the surcharge was usually around 4kg.

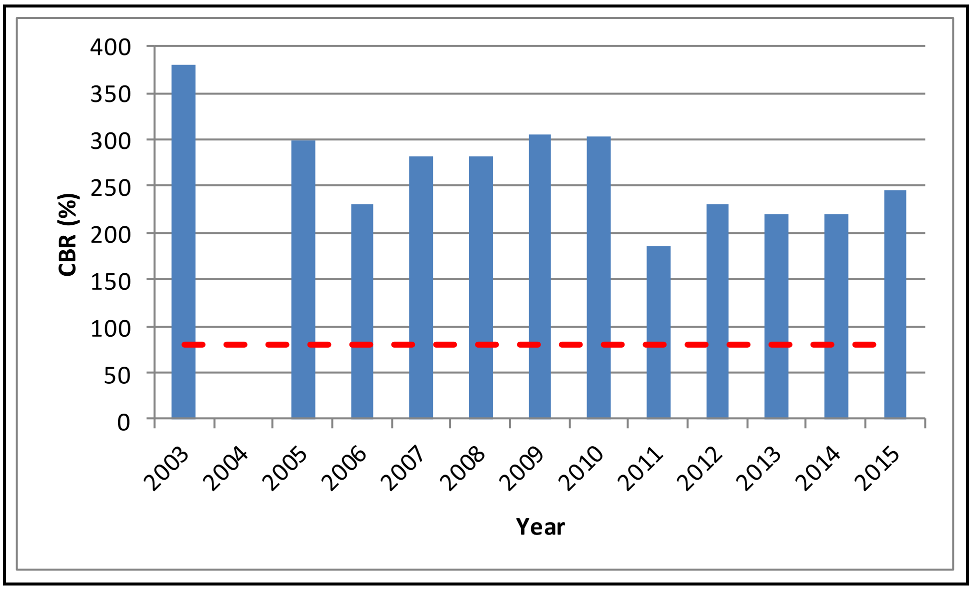

Figure 4.9 Average California Bearing Ratios for Transit AP40 aggregate tested each year from 2003 to 2015. The red dashed line indicates the minimum value (80%) required for compliance with the TNZ M/4 specifications.

For this research both the T-Grade and C-Grade material had five samples tested, whereas the G-Grade material was tested on six samples; this was the result of some material not arriving on site in Christchurch. The results ranged from 155% to 485%, all greater than the minimum requirement of 80% (Figure 4.10). The G-Grade material had the lowest average of 202% and the T-Grade material performed the best with an average of 289%; the C-Grade material performed similarly to the T-Grade material with an average of 269%.

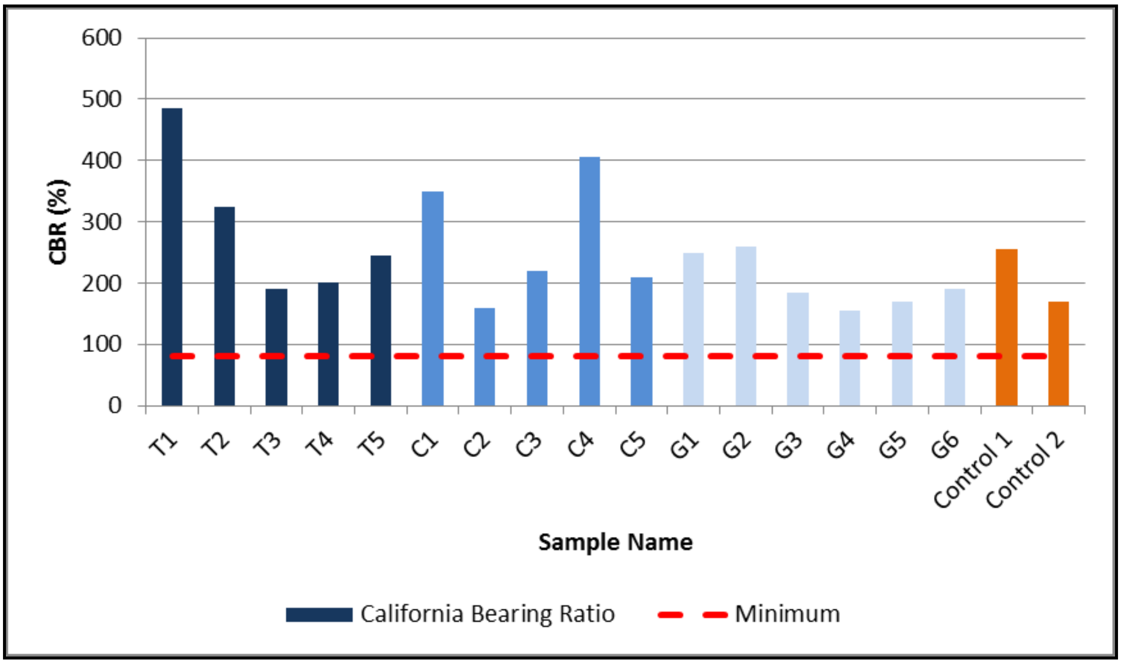

Figure 4.10 California Bearing Ratio (CBR) for T-Grade, C-Grade, G-Grade and Control sample basecourse aggregate. T = T-Grade C = C-Grade, G =G-Grade. Red dashed line indicates the minimum allowable CBR value accepted for the specification.

The statistical analysis of the CBR data indicates each year and grade shows some variation, with the most occurring for the T-Grade material which also had the highest value (Figure 4.11). The C-Grade material had a large range between median and upper quartile compared to the other groups. The samples tested between 2012 and 2015 had relatively consistent medians and little variation between each year. This material was obtained from differing areas in the quarry but still produced a similar range in results. 2014 produced the lowest single result but 2011 had three quarters (third quartile) of the results considerably lower than the others. This may indicate rock of lower strength which is expected with the G-Grade material as it is more weathered and produces a lower WQI, but any variations above 200% are considered negligible. There is a difference between all the results before 2010 and those after, which the results in the latter years having a generally lower CBR value.

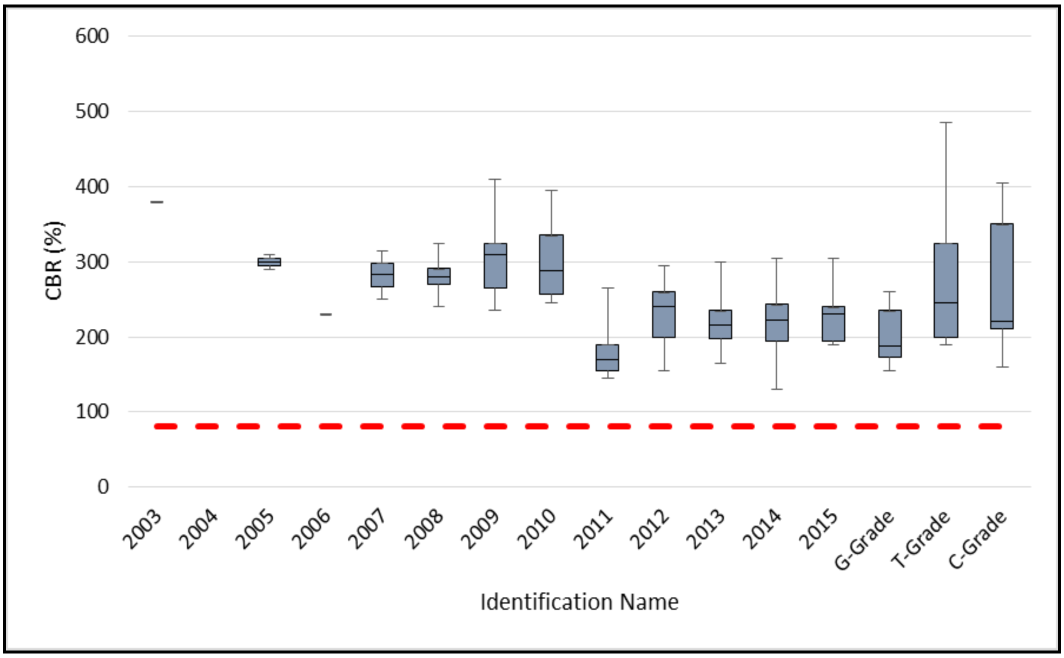

Figure 4.11 Crushing Resistance Box Plot for all historic test reports and the results from the three weathering grades. Some years had insufficient data (one result) to formulate a box plot and therefore are indicated by a line.

4.5 Quality of Fines

The Quality of Fines includes the Sand Equivalent, Clay Index and Plasticity Index test results from 2003 to 2015, and the results from this research for both the current and draft specification.

4.5.1 Sand Equivalent (SE)

The Sand Equivalent was tested in accordance with NZS 4407: 1991, Test 3.6 *Sand Equivalent Test*. The average Sand Equivalent exceeded the specified minimum of 40 for every year of the historical data study period, (2003 to 2015). Sand equivalent is an indicator of the relative proportions of the sand fines but doesn't necessarily give an accurate indication of what the types of fines are or if there are deleterious clays present.

Figure 4.12 displays the average of the results from each year. The minimum annual average was 48 in 2011 calculated from 29 samples, and the highest was 63 in both 2005 and 2006. In 2006, 2010 and 2011, there were some samples which did not pass as material had too many fines when compared to the coarse particles. The lowest recorded result was 33 in late 2011 and the highest was 83 in November 2005. A low result indicates the fines to sand ratio is high; the majority of failed samples had values greater than 37, which is close to the limit of 40.

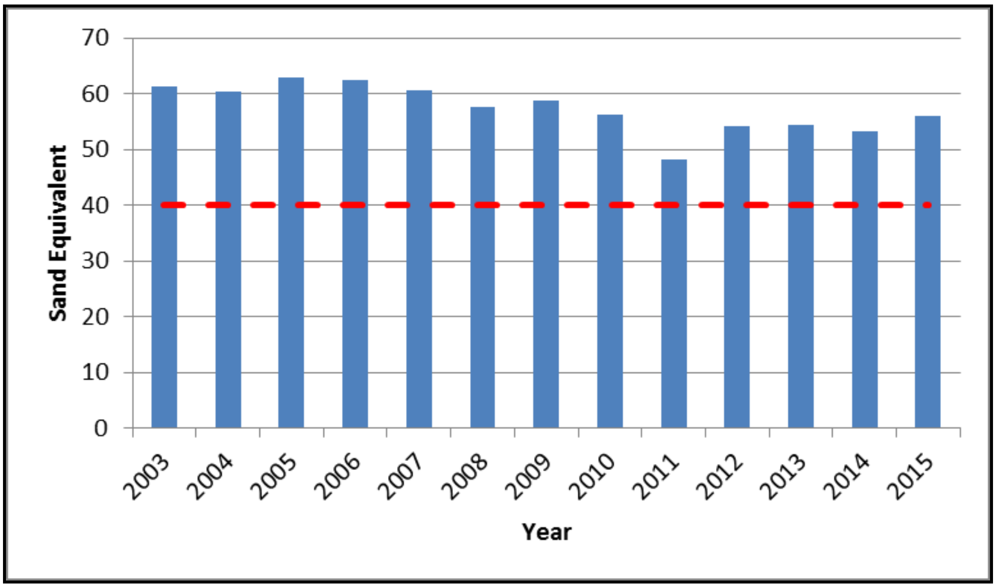

Figure 4.12 Average Sand Equivalent for Transit AP40 aggregate tested each year from 2003 to 2015. Red dashed line indicates the minimum value (40) required for compliance with the TNZ M/4 specification.

Six samples from each weathering grade were tested at the PLQ laboratory and the results are displayed in Figure 4.13. The lowest SE value was 39 from the T-Grade material, and was the only sample that failed the test. The highest SE value was 62 from the C-Grade material indicating good ratio of fines to sands. The average SE values for the T-Grade, C-Grade and G-Grade were 50, 54 and 55 respectively. The control stone did not meet the specification which is a common result, but passes the specification as it meets the other quality of fines requirements.

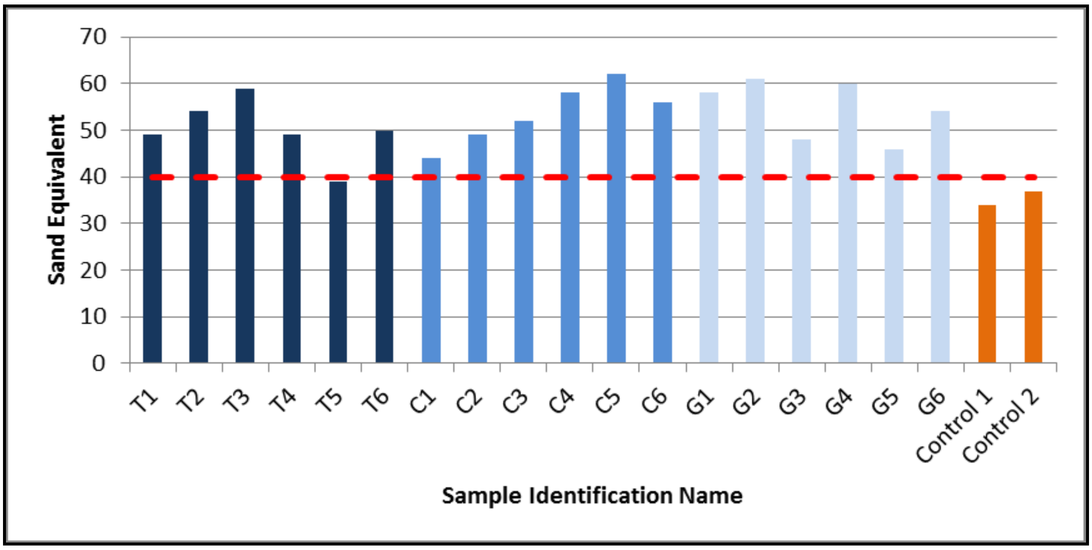

Figure 4.13 Sand Equivalent for T-Grade, C-Grade, G-Grade and Control sample basecourse aggregate. T = T-Grade C = C-Grade, G =G-Grade.

There were no amendments to the SE section in the draft NZTA M/4 specification, and no new data analysis was required.

The sand equivalent consistently meets the specification with some variability through each year (Figure 4.14). In 2011 had the lowest third quartile which coincides that it had the lowest average results over the study period. This indicates a higher fines percentage and may be attributed to aggregate breakdown or a change in the production process.

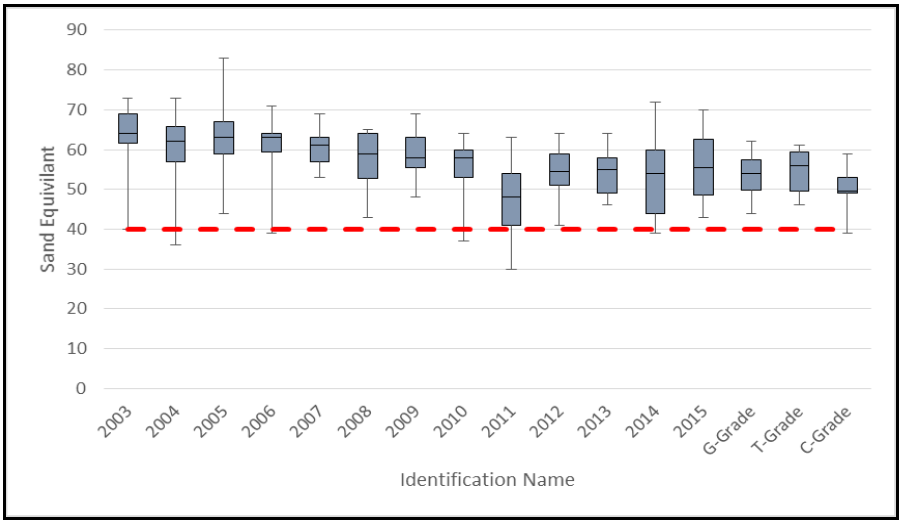

Figure 4.14 Sand Equivalent for all historic data from 2003 to 2015, and the results for the three weathering grades T = T-Grade C = C-Grade, G =G-Grade.

It is expected that the higher the SE the lower the Clay Index value should be, as a higher SE indicates a lower fines concentration. This was plotted for the research samples but no obvious trend was found. In fact the data showed an opposite trend, where the higher the SE the higher the CI (Figure 4.15). The historic data could only be compared by averages for each year (Figure 4.16) as none of the test results came from the same sample, and these would be unreliable. This too followed the trend of higher SE and higher CI for the research data set, which is inconsistent with industry expectations. This could be attributed to the clay index test and results: methylene blue used in the CI test can interact with particles that have a charge, and may indicate a higher clay content than what is actually present. The R^2 value for the historical data is 0.1511 and for the three weathering grades it is 0.1124, this shows that it may appear to follow a trend but isn't very reliable.

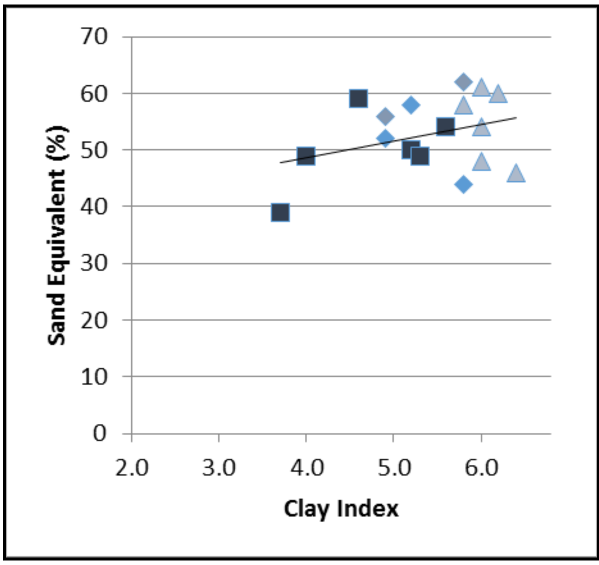

Figure 4.15 Comparison of the SE and CI data from the three weathering grades. Squares represent the C-Grade samples, Triangles present the G-Grade samples and the diamonds represent the T-Grade samples. R2=0.1124

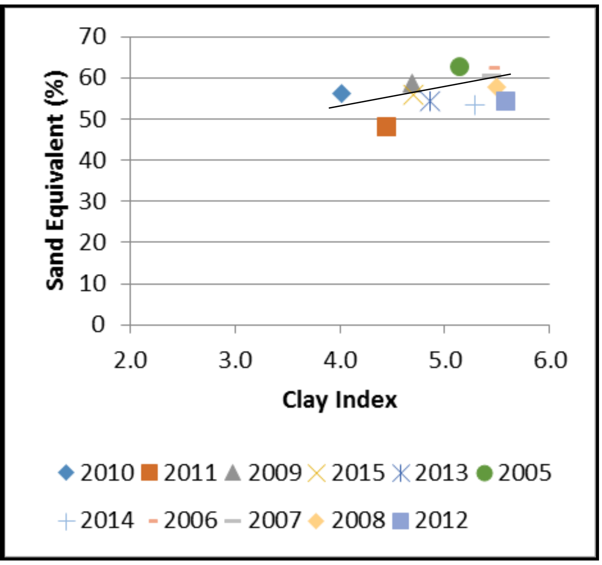

Figure 4.16 Historic data average results comparing the SE and CI. R2=0.1511

Research indicates that these tests don't allow for accurate representation of the fines to sand ratio, as the settling times may vary between rock types (Lowe, et al 2010). This may be the case for PLQ, as both sets of data are similar and display an opposing trend to what is expected.

4.5.2 Clay Index (CI)

The Clay Index test was conducted in accordance with *NZS 4407: 1991, Test 3.5 Clay Index Test.* Records of the Clay Index test are only available from 2005 to 2015. The specification requires a maximum CI of 3. All the CI values over the historical study period were greater than this, with no single test falling within the specification range (Figure 4.17). This has been of particular concern for the production and use of the M/4 AP40 basecourse, as the presence of clays may be deleterious, especially in the case of expansive clays. Non-compliance with the CI specification does not necessarily constitute failure of the basecourse, as the specification requires that only one of the Quality of Fines conditions be met. The highest CI value of 10.8 was recorded in 2012; this is not represented in the graph of average values (Figure 4.17), but is accurately displayed in the frequency distribution graph (Figure 4.7). The lowest value of 3.1 was recorded in 2010, which is only slightly greater than the specified value for compliance.

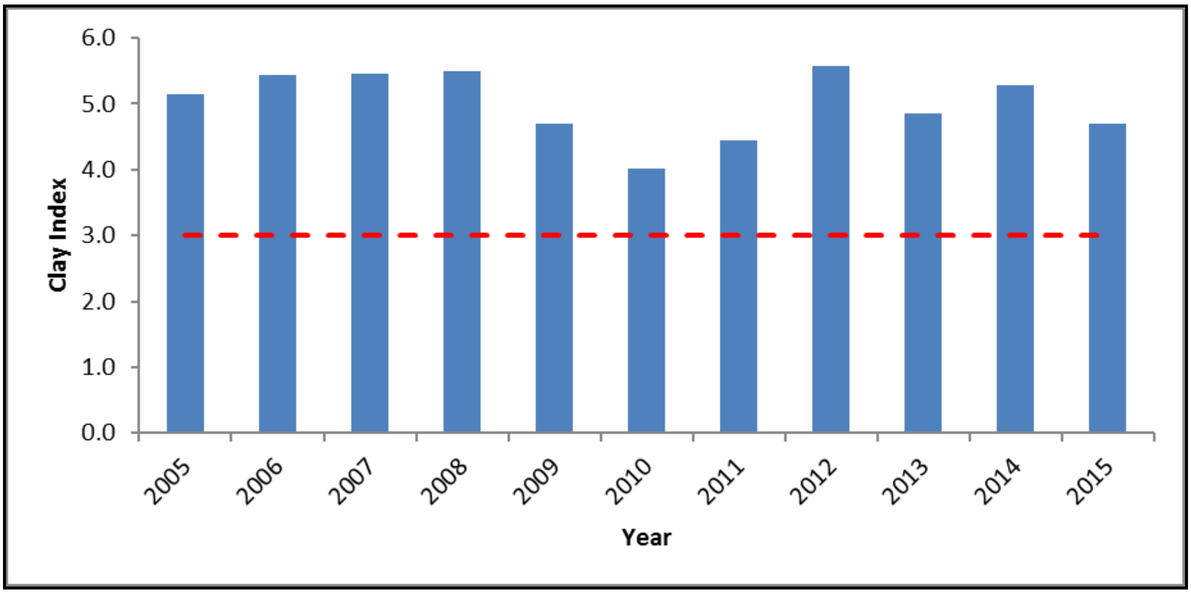

Figure 4.17 Average of Clay Index values for Transit AP40 aggregate each year from 2003 -2015. The red dashed line indicates the maximum value allowed by the TNZ M/4 specification for compliance.

A graph was populated to display the variance of CI results over the years, with individual sample results shown in Figure 4.18. This accurately illustrates the variance between the results, and as with the frequency distribution graph (Figure 4.19), it indicates that the majority of CI values fall between 4.6 and 5.1.

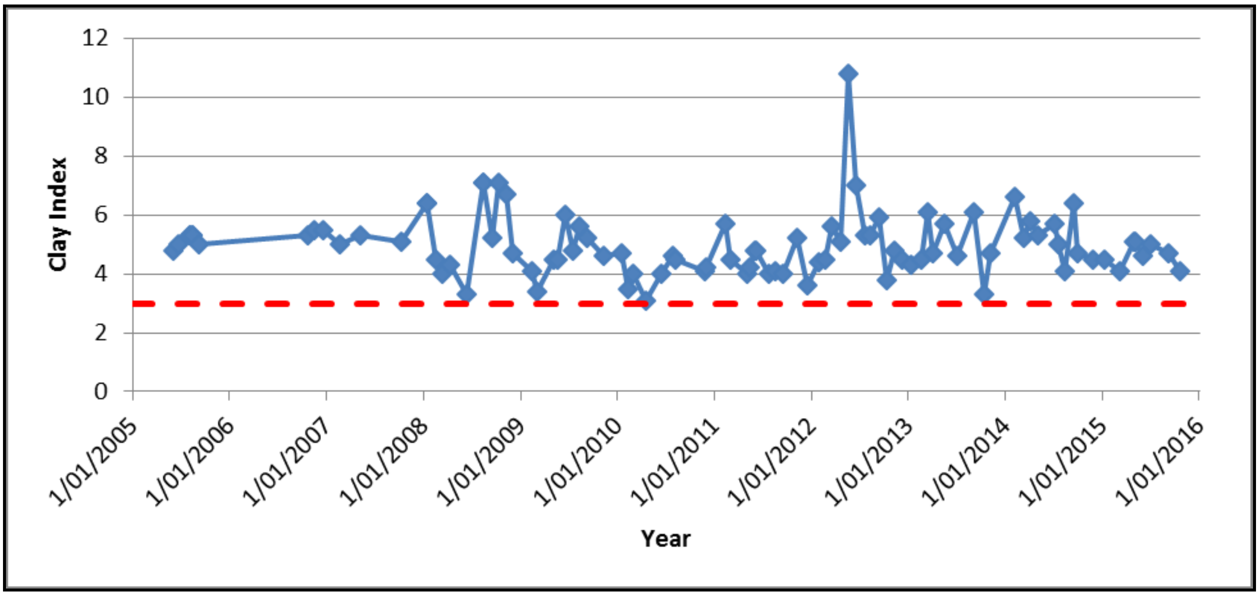

Figure 4.18 Clay Index values for Transit AP 40 aggregate from 2005 to 2015. Red dashed line indicates maximum value (3) allowed for compliance.

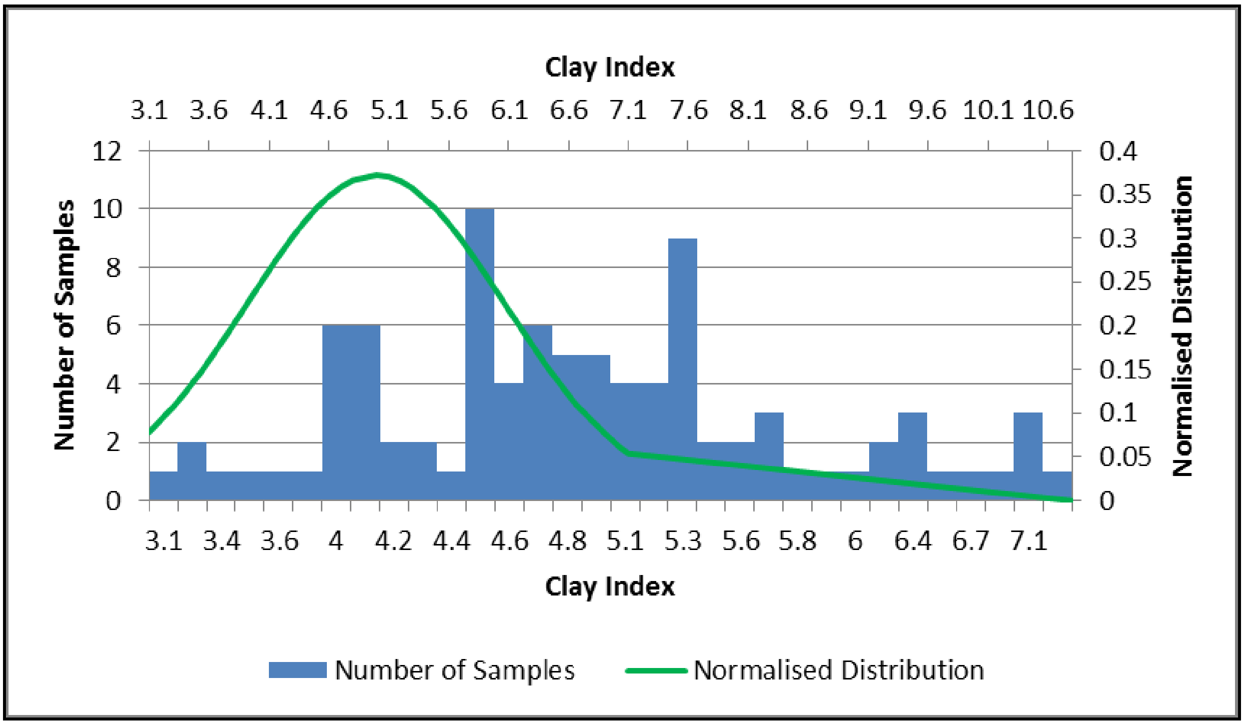

Figure 4.19 Frequency Distribution and Normalised Distribution graph for Clay Index values for Transit AP40 aggregate from 2005 to 2015. The maximum permissible value for compliance with specifications (CI = 3) is not shown, as none of the test results fell on or below this value.

For this research six samples from each weathering grade were tested and the results ranged from 3.7 to 6.4, none of the samples complied (Figure 4.20). The T-Grade material had the lowest average of 4.7, the average for the C-Grade material was 5.6 and the G-Grade material had the highest average of 6.1. The greywacke control stone passed the specification with both samples having a CI of 2.

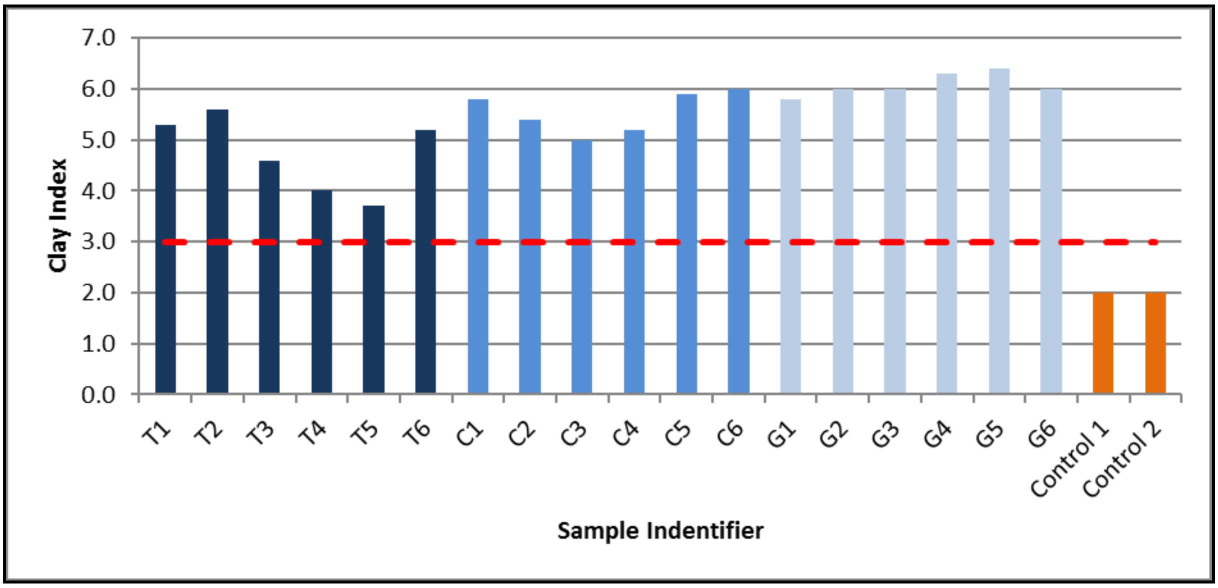

Figure 4.20 Clay Index (CI) compliance with the TNZ M/4 specification for the T-Grade, C-Grade, G-Grade and control stone aggregate; the dashed red line indicates the upper CI limit (CI = 3), T = T-Grade C = C-Grade, G =G-Grade.

The Weighted Clay Index test was applied in accordance with the NZS 4407: 1991, Test 3.5 *Clay Index Test and* Test 3.8.1 *Wet Sieving Test.* The values obtained from the 75 µm sieve in the PSD test and the CI results from this laboratory research were used to calculate the Weighted CI (Figure 4.21). The results from the three weathering grades (six samples each) ranged from 14.8 to 30: the draft NZTA M/4 specification stipulates that 15 is the maximum allowable value for the Weighted CI. The only sample that passed the test was T5 (T-Grade) with a CI value of 14.8. The average Weighted CI values for each grade were 23.1 for both the T-Grade and C-Grade material, and 26.2 for the G-Grade material. This can be expected as the G-Grade is the most weathered. The control stone had a value of 10 which passed the specification.

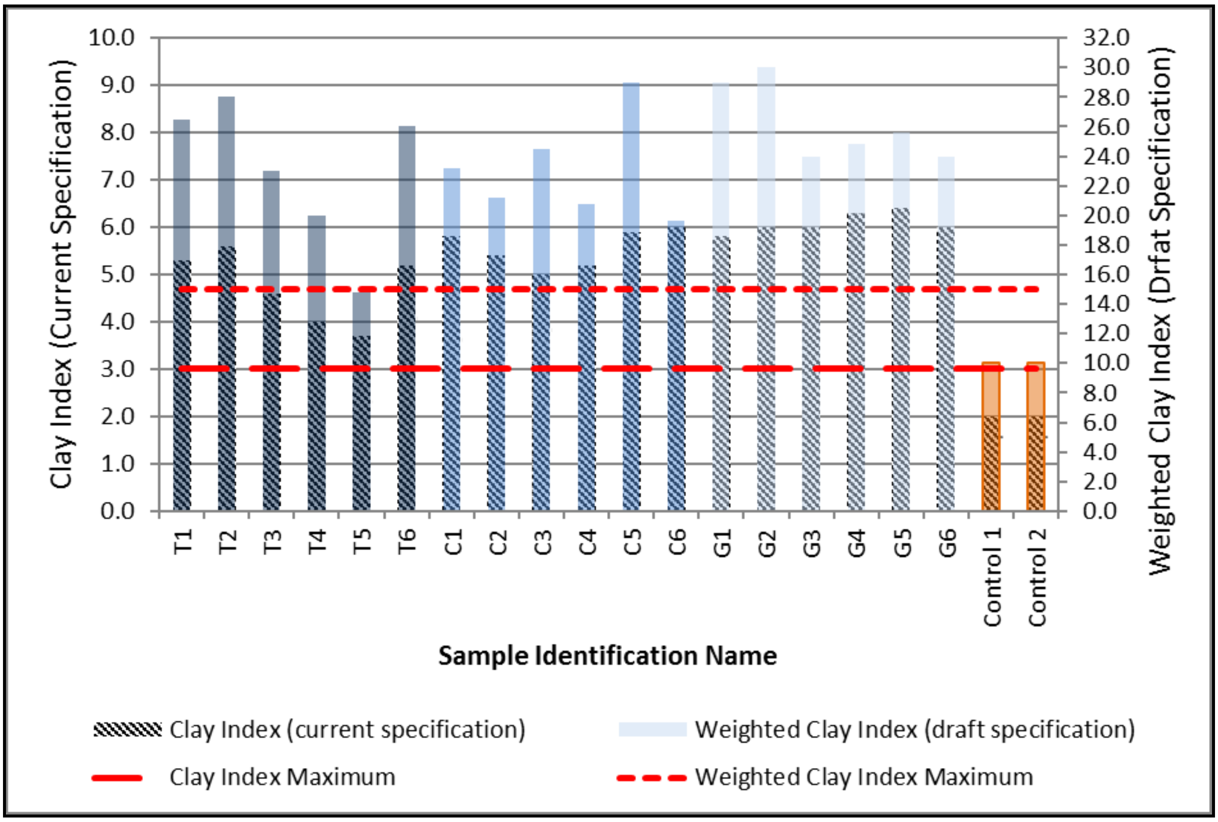

Figure 4.21 Clay Index (CI) and Weighted CI test results and compliance with the current and draft TNZ M/4 specifications T-Grade, C-Grade, G-Grade and Control sample basecourse aggregate. T = T-Grade C = C-Grade, G =G-Grade. The lower dashed red line indicates the upper CI limit in the current TNZ M/4 specification (CI = 3), and the higher red dashed line indicates

Clay Index results indicated variability throughout the years, including the results from the research samples (Figure 4.22). The G-Grade material had the least variability but also the highest overall values between the three weathering grades. The highest recorded value was in 2012, although the mean of this year was similar to that of 2004-2008 and 2014. As noted in the results section, all the CI results were above the specified limit of 3. The CI index test is not reliable for indicating the type or amount of clays. Any mineral with a surface charge or irregularity will react with the methylene blue used as a clay indicator for this test, and will display the presence of clays and more commonly perceived deleterious minerals. The Clay Index test is carried out on the silt fraction, and not the clay fraction only, so any material within that silt fraction that has the potential to react with the methylene blue will do so and could indicate a higher CI value.

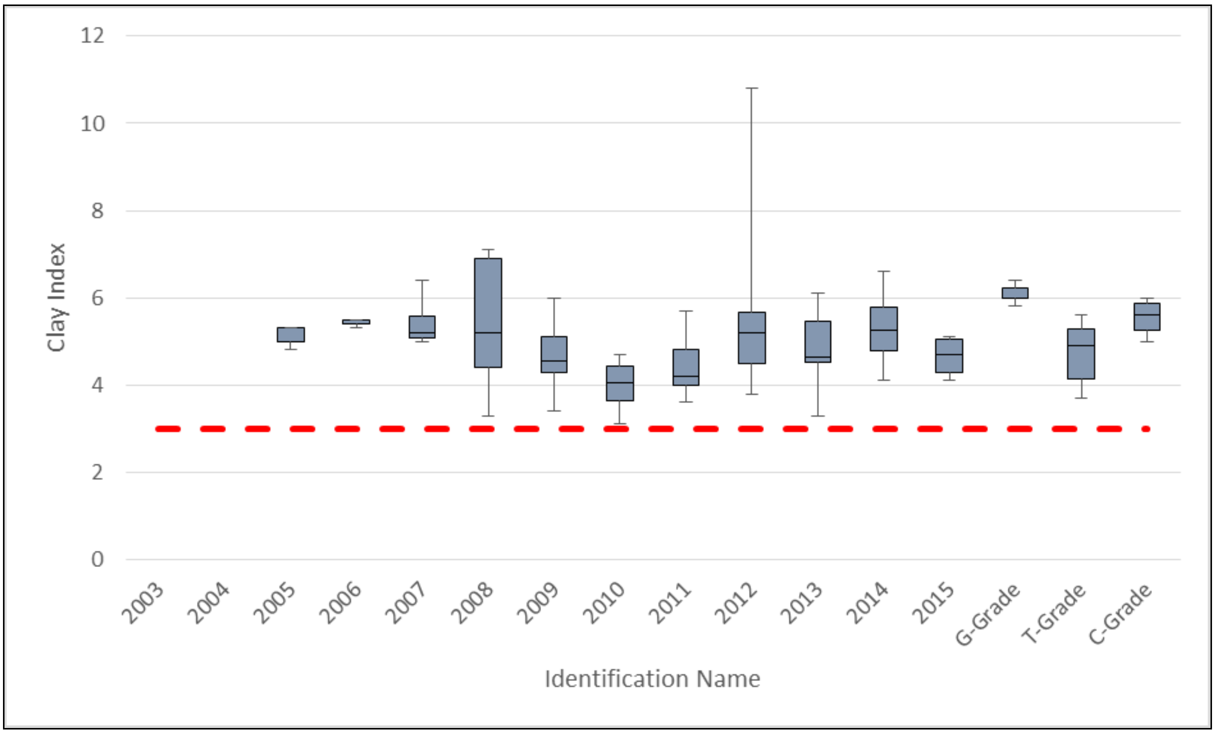

Figure 4.22 Clay Index results for the historic data from 2003 to 2015 and the three weathering grades. Years with no box plot had no results recorded for that year

Weighted Clay Index (WCI)

The historic data was collated for all data points where the percentage passing the 75 µm sieve and the CI were recorded. The WCI was calculated and then plotted against the corresponding CI values. The 72 data points used were calculated as a percentage increase from the limit of 15 for the WCI and, 3 for the CI (Figure 4.23). There is no clear representation as to how the WCI will affect the results. Lowe, et al (2010) indicate that the WCI should provide a more suitable indication of clay content. It can then be expected that comparing the CI and WCI will display some variability (where the WCI is higher, lower or the same as the CI), as displayed in figure 4.23. As all results were above the limit the average percentage increase was determined for each specification limit, CI = 3 and WCI = 15. Over the 72 data points there was an average increase of 164% for the CI and 177% for the WCI, this difference is considered not significant. The WCI may be of concern as the average results tend to show a larger increase, although both sets of data are made up of samples which fail to meet the specified limit.

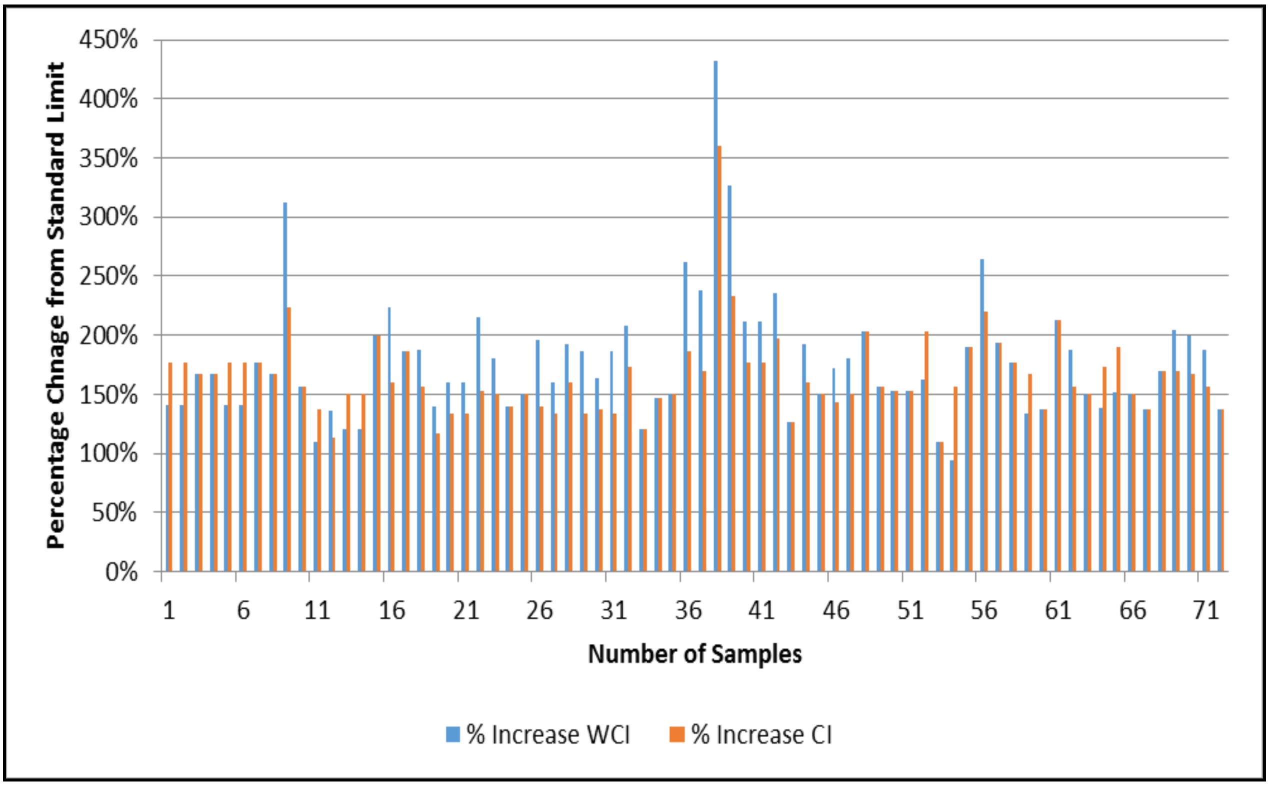

Figure 4.23 Percentage change from the respective limit for all historic results recorded for both the CI and WCI

The results for the three weathering grades are similar to that of the historic data, with all bar one exceeding the limit (CI = 3, WCI = 15). Therefore the percentage increase from the limits were graphed (Figure 4.24). The percentage increases for the WCI is never greater than that of the CI percent increase. The average percentage increase for the CI was 182%, similarly the average percentage increase for the WCI was 163%. This increase, although it can be passed as negligible, indicates that by using the average WCI the results may appear better than they would had they not been weighted.

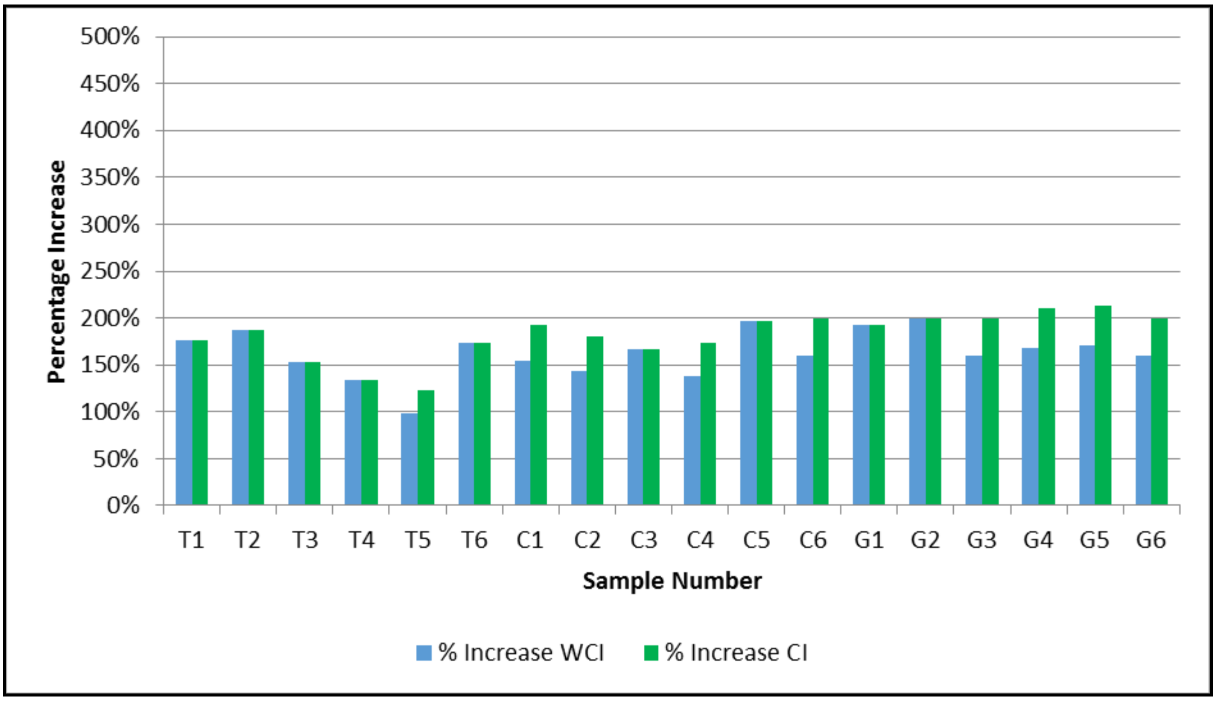

Figure 4.24 Percentage change from the respective CI and WCI limit specified for the three weathering grade results.

The high clay index results can be attributed to the reactive clay content of the material; as previously discussed, this might not be as accurate as the test implies due to the nature of the particles, and their reaction to the methylene blue. The reduction in CI is difficult to achieve without changing the grading of the material or including fines from another source, which could result in the material not meeting the specification. The requirements specify that the basecourse shall meet two of the four Quality of Fines criteria, so although it is important to have an understanding of what the CI is, it might not be detrimental for the use of the product.

4.5.3 Plasticity Index (PI)

The Plasticity Index is tested in accordance with NZS 4407: 1991, Test 3.4 *Plasticity Index Test*. The Plasticity Index of the historic test material showed a large variation over the study period (Figure 4.25). There was no recorded data from 2003, 2004 and 2006. Compliance with the specification requires that the PI value be no more than five; from 2010 onwards the average PI values for each year have been greater than the specified limit. There was also a variance within the results; some samples have proved to be non-plastic (PI = 0) and other samples have values as high as 17. This clearly indicates non-compliant plasticity for some of the material. The averages are brought down considerably by the non-plastic samples, which were given a result of zero for representation. The number of samples tested each year varied between 3 and 12. The Plasticity Index of a material is heavily dependent on the clay type and content. The more plastic the clays are the more likely a higher PI reading will be achieved. Smectite clays are more plastic as they are hydrous clay minerals whereas Kaolin clays and anhydrous and more likely to be behave as non-plastic.

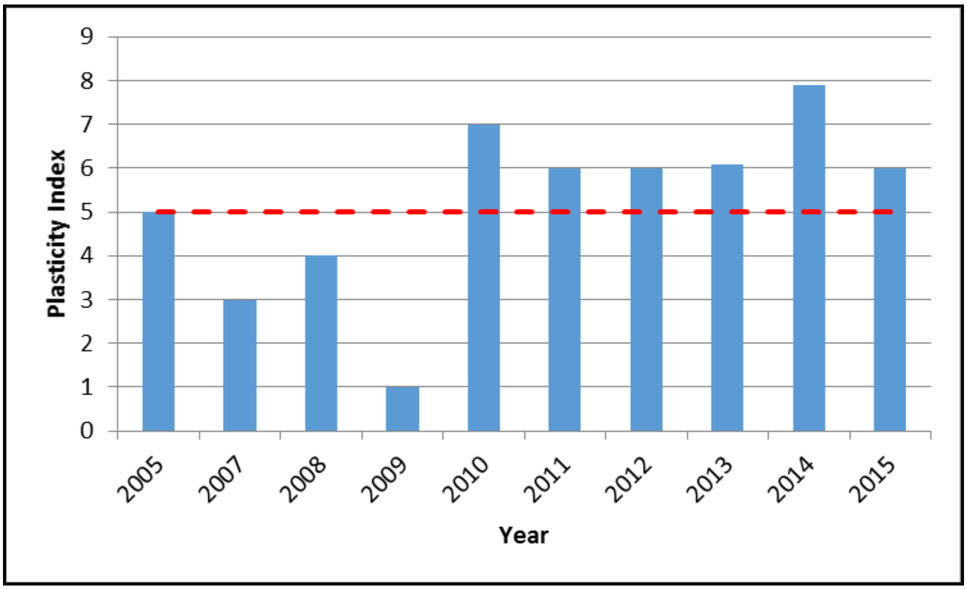

Figure 4.25 Average Plasticity Index (PI) values for each year from 2004 to 2015. The red dashed line indicates the allowable maximum PI of 5, which is specified in the TNZ M/4 standard.

Individual PI values are displayed in Figure 4.26, and show the variability within the results. Compliance with PI specification requirements is demonstrated by only 51% of samples, and more than 35 samples were non plastic (Figures 4.26 and 4.27). Indeed, after 2013, the vast majority of results are not compliant and there are no non-plastic results.

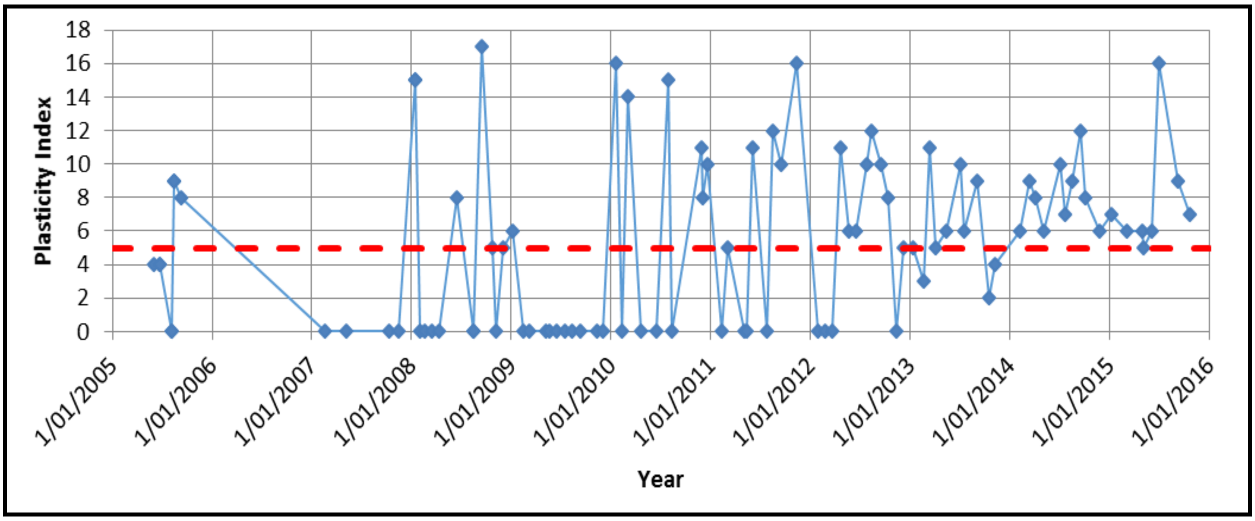

Figure 4.26 Plasticity Index (PI) values recorded from 2005 to 2015. Non-plastic results are represented by a zero value. The red dashed line indicates the maximum PI value allowed for compliance with the specification.

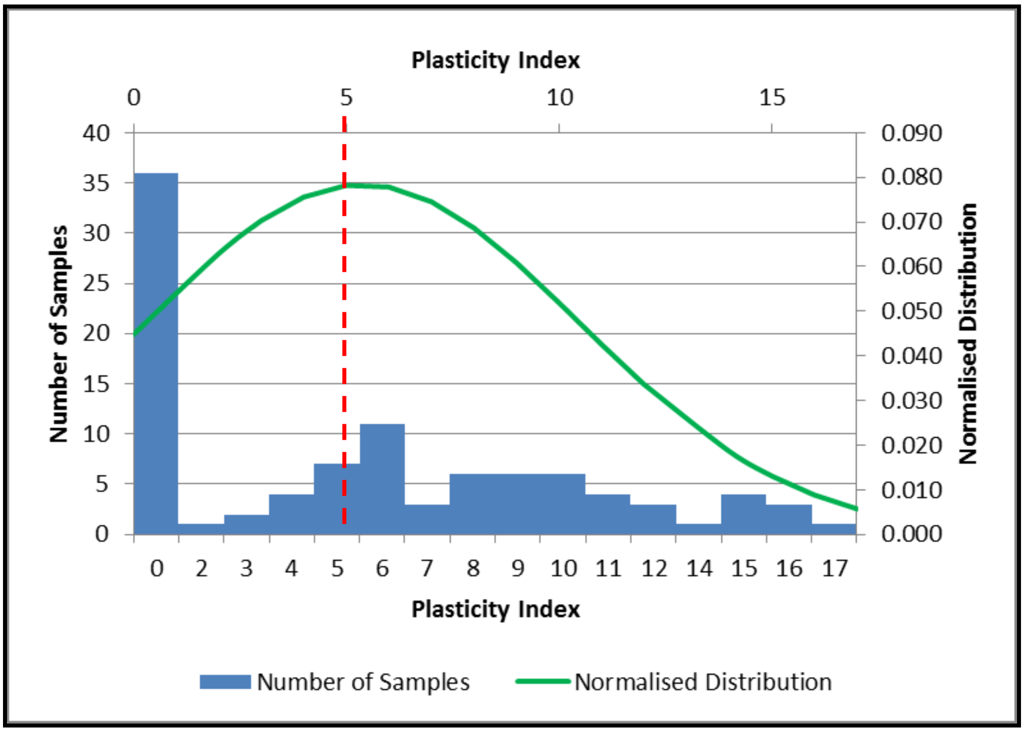

Figure 4.27 Frequency Distribution and Normalised Distribution for Plasticity Index values for the Transit AP40 aggregate 2005-2015. Red dashed line indicates the maximum value for compliance with specifications, PI = 5.

All 18 samples collected for this research were non-plastic; the maximum permissible PI value is 5 for the current TNZ M/4 specification, therefore all the samples passed the test. This is dissimilar to that of the historic results in the latter years.

The Weighted PI value was not calculated as the results would still return a value of 'non-plastic'. The maximum Weighted PI value for compliance with the draft NZTA M/4 specification is 40; all samples would pass this requirement.

The plasticity results indicate a large variation over the years, with 2008 having the most variation and the highest results, as well as having non-plastic material (Figure 4.28). All the samples collected for this research had material that was non-plastic. The variability can be attributed to a number of factors, one being the variability of the fines within the quarry; changes in the composition of the rock can have an effect on the PI result. Another possible reason for the vast differences is the competency of the technician conducting the test. Bartley (1988) reported that as far back as 1958 it was made apparent that Plasticity Index results varied between technicians based on their competency. This is because a PI result is attainable even if the material is non-plastic. It takes a trained skilled person to identify the difference. In saying that, results as high as 17 are likely to be correct, the errors would probably be in the material with a low PI value as it would act similarly to that of a non-plastic sample and could easily be incorrectly identified as non-plastic.

The Plasticity Index testing completed for PLQ have been contracted out to external laboratories and have been conducted by many different technicians. In Years 2008, 2010, 2011 and 2012, the majority of results were in the lower quartile, likely due to the number of non-plastic results (which are recorded as zero for graphing purposes).

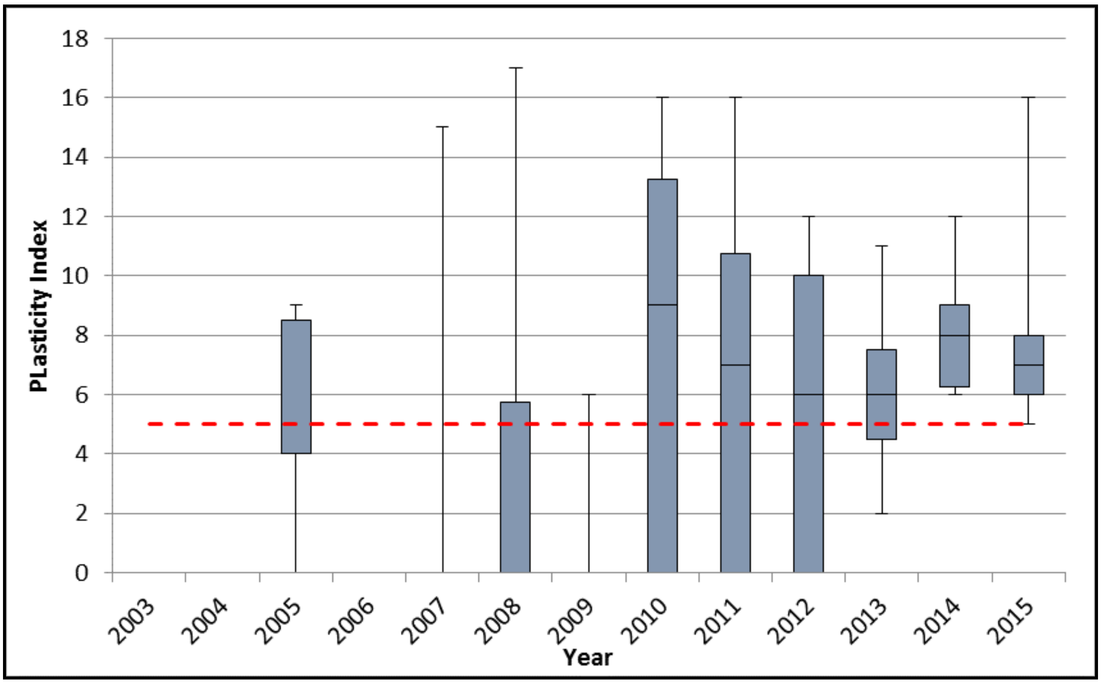

Figure 4.28 Plasticity Index box plot results from the historic data. Where no box plot is shown, this indicates a year where no PI values were recorded

Personal communication with D. Topp (2015) highlighted that the AP65, a material with a larger nominal size, consistently passes the PI and is usually non-plastic. This is likely due to the processing procedure. The larger fraction size is not subject to the same magnitude of crushing as the AP40 is, so less aggregate breakdown occurs and ultimately less fines are introduced into the final product.

The normalised distribution shows that the majority of results were recorded as non-plastic, which creates a left skewed graph, with the mean situated around the limit of 5 (Figure 4.29). The normalised line does not fit the frequency distribution very well. This is because of the number of non-plastic results; when removing the non-plastic results, the graphs fit well but do not display the significant number of non-plastic values, so is unrepresentative.

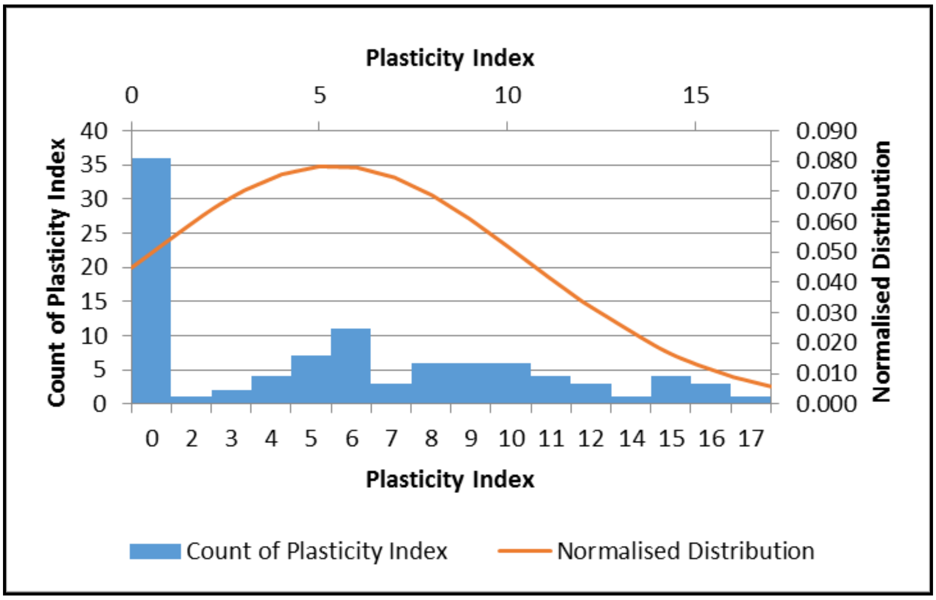

Figure 4.29 Normalised Distribution and frequency graph for all historic PI results

All the Clay Index and Plasticity Index (PI) were plotted against one another to determine if any trends exist within the data (Figure 4.30). Only data from the same test reports (the same sample) were used. From the graph it is apparent that very little correlation exists between the two sets of data. Historic research indicated that smectite clays were present in the aggregate which could lead to a higher plasticity index, this could explain some of the results. It is likely that there is variability within the quarry, in both clay type and content, which leads to the variability in the results. The R^2 value for this data is 0.0074 which indicates no correlation between the CI and PI. The clay type might contribute to the variances within the PI, if different types of clays are present this will result in different PI values. Kaolin group clays will likely produce a non-plastic or very low plasticity index results whereas smectite minerals such as montmorillonite can result in PI values much higher than other clay minerals (Bain, 1971). This also may give an indication as to why there are so remarkably high results.

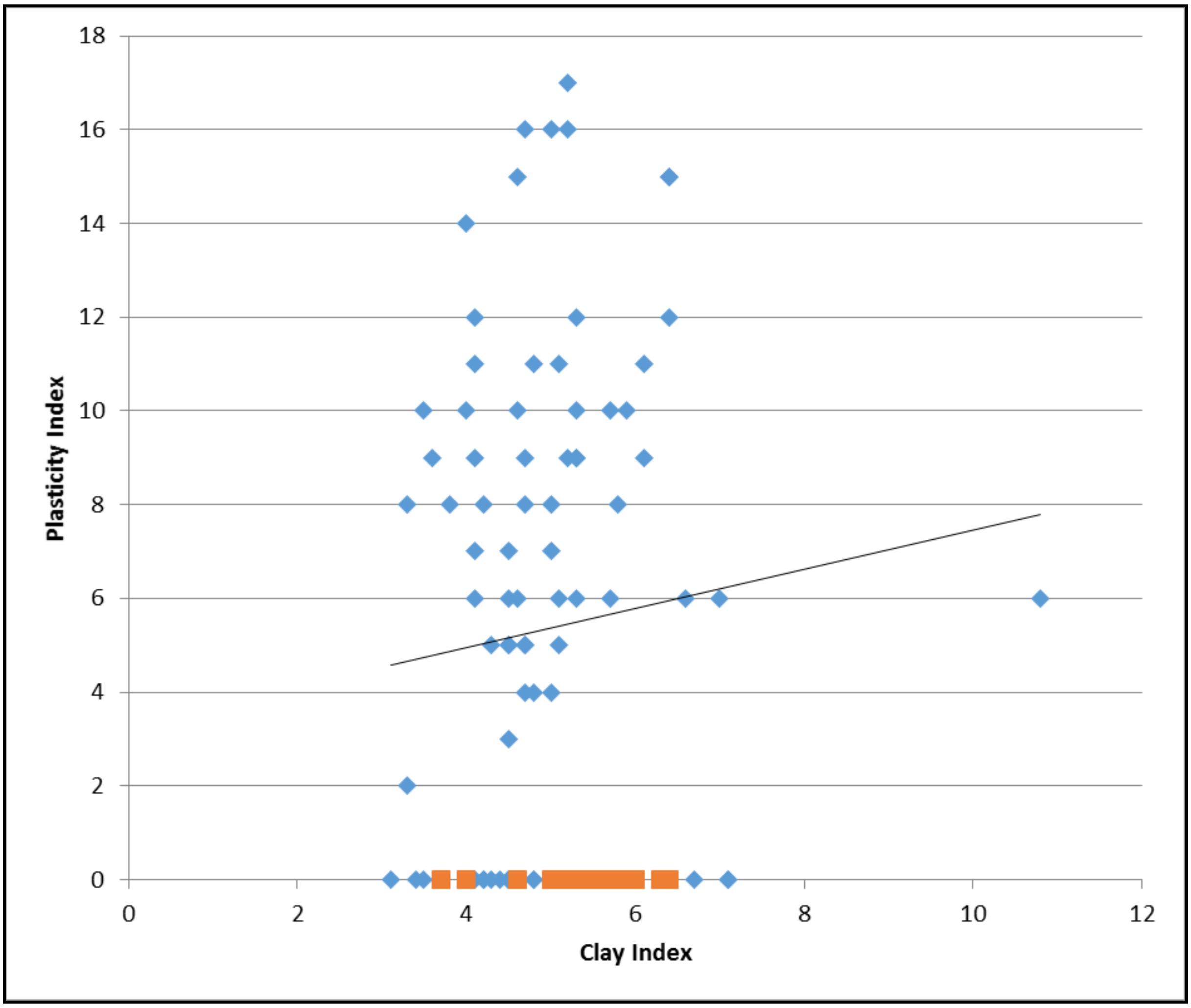

Figure 4.30 Comparisons of PI and CI. Displaying all historic data where test reports correlated. The orange squares represent the three weathering grade results (all were non plastic)

Weighted Plasticity Index (WPI)

The WPI was not calculated as all of the research samples had non-plastic material and all historic results did not have the 425 µm grading to determine the value. The WPI is calculated by multiplying the PI value by the grading percent passing the 425 µm sieve. It was investigated to determine whether the 425 µm grading could be calculated from the original PSD gradings (i.e. reference form the sieves above and below the 425 µm sieve). The results of this investigation and a detailed discussion can be found in Appendix B. It was determined that using a calculated grading would not be sufficient in accurately identify the grading percentage over the 425 µm sieve and that an actual grading of the material should be conducted. This can be easily included into the routine PSD gradings with the addition of the sieve.

4.5.4 Sand Grading Exponent

The Sand Grading Exponent (SGE) has only been included into the draft NZTA M/4 specification and a detailed explanation as to why it was introduced can be found in Appendix C. The results from the historic data and material tested for this research has been used to determine the consistency of the SGE. The SGE was calculated for each year and then averaged (Figure 4.31). The highest SGE was 0.63 recorded in 2003 and the lowest SGE of 0.25 in 2005. Each year some of the samples failed, with the most failures occurring during 2010 where 44% of the samples had the SGE below 0.4, with most between 0.36-0.39. This is notable in Figure 4.24 where 2010 has the lowest average. In 2015, the latest testing, only one sample returned an "uncertain" result. Uncertain refers to a result which is lower than the 0.4 limit.

The three weathering grades of material tested for this research all had SGE values above the minimum limit of 0.40, with the highest values recorded for samples C1 and C6, each with a value of 0.54. The average values for each group were 0.48 for the Transit material, 0.52 for the C-Grade material and 0.51 for the G-Grade material.

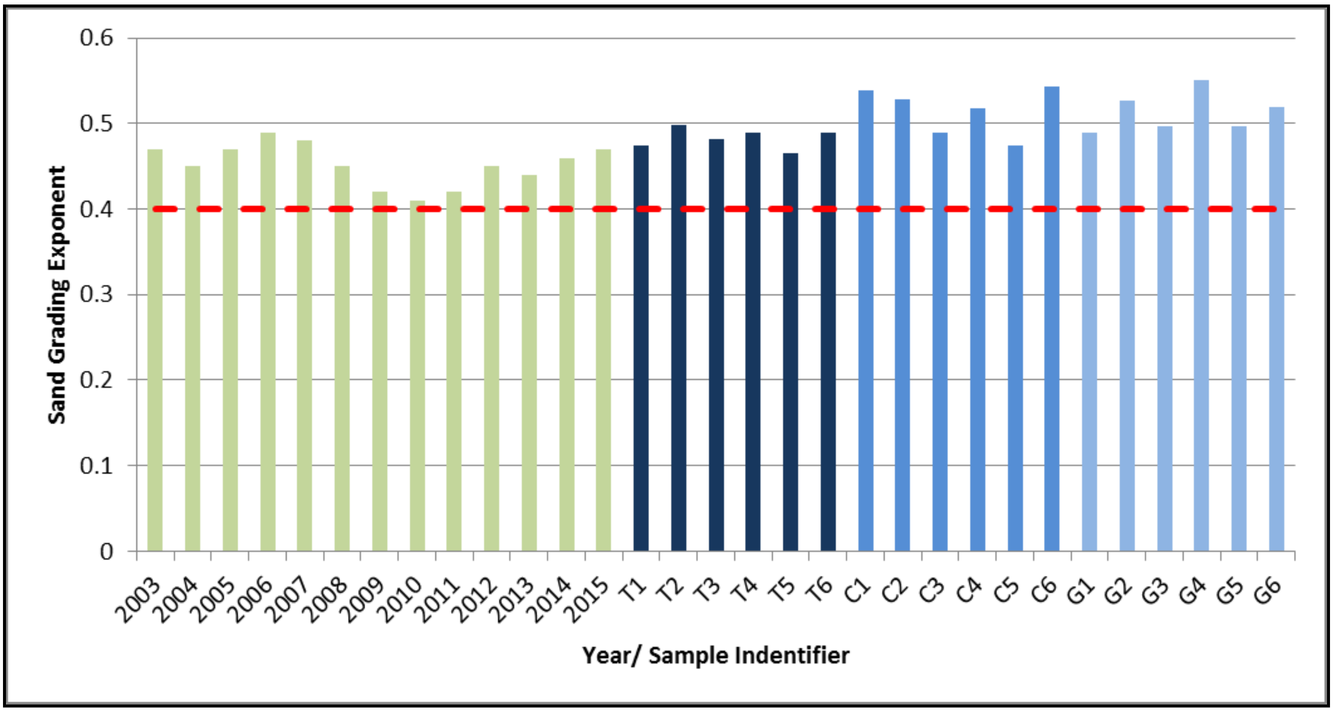

Figure 4.31 Average Sand Grading Exponent (SGE) for each year from 2003 to 2015 and the SGE for individual samples of the three weathering grades of material (T = Transit, C = C-Grade, G = G-Grade). The red dashed line indicates the minimum SGE value required for compliance (0.4) in the draft NZTA M/4 specification.

The PLQ aggregate tested for this research performed well against the SGE with all samples having values greater than the specified limit of 0.4. This means that the PLQ aggregate is graded well and not lacking in material in the sand fraction. The specification specifies the "sand" range from 4.75 mm – 0.15 mm sieves as these were the areas that were identified as missing in Steven and Salt's (2011) research. When reviewing the historic results some samples did fail the SGE, with results as low as 0.25. This was not very common, but should be considered as each year produced some material which was gap graded (a SGE of less than 0.4). From 2003 to 2007 the PSD did not consistently fall within the specified grading envelope. In these years it can be expected that some fractions were not to standard and a low SGE can be expected.

The draft specification details the sand fraction as the particle sizes which fall between the 4.75 µm and the 150 µm sieve. The highest and lowest SGE result gradings show that although the grading may fall out of the envelope and therefore not meet the specification, it is the grading between the critical fraction sizes which are the determining factors.

Sample PR5663 from 2003 had the highest SGE of 0.63 but was too fine in the coarser fraction (Figure 4.32). Between the critical fraction sizes it consistently followed the envelope boundary. Sample R9337 only slightly deviated from the grading envelope and was too fine in both the largest and smallest fractions. In the critical fraction range (identified by the dashed blue lines in figure 4.32) it was not consistent moving from one limit to the other, this indicates that the sample was gap graded in the sand fraction.

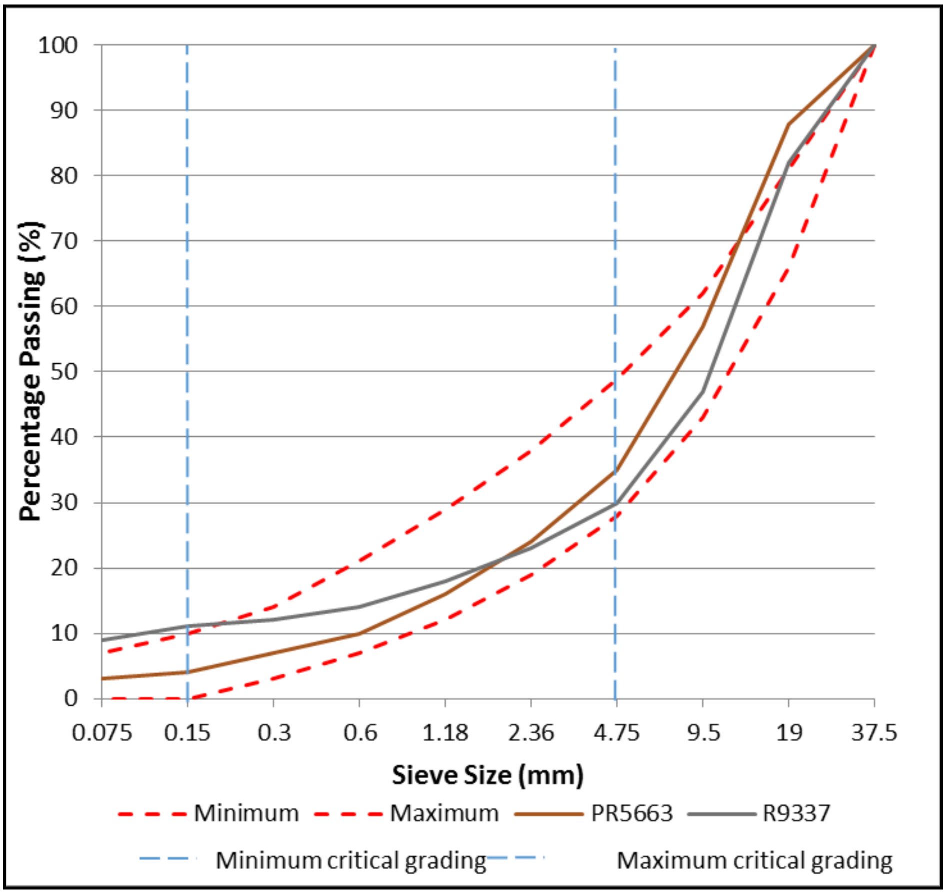

Figure 4.32 Grading for two samples, PR5663 representing the sample that had the highest SGE and R9337 representing the sample which had the lowest SGE and gap graded in this part of sand fraction. Note how the R9337 sample moves across the grading envelope.

This indicates how the consistency of the grading and the deviation from the envelope between these ranges are critical in obtaining a positive SGE result. Even though the addition of the SGE specification would not adversely affect the PLQ aggregate, monitoring of the material is essential to ensure it meets the standard for every sample.

4.6 Broken Face Content

The nature of the quarrying process, which includes blasting and crushing, results in an aggregate with broken faces on all sides, but the current standard requires only two or more faces to be broken so the aggregate will always meet this specification. This specification relates mostly to river gravels, which have rounded faces. The more angular and rough the surface of the stone is, and it less rounded surfaces there are, the better the interlocking matrix of the basecourse will be in the pavement. All test reports on the samples of TNZ M/4 AP40 aggregate from 2003-2015 have indicated 100% broken faces for the three specified fraction sizes (37.5 mm - 19.0 mm, 19.0 mm - 9.5 mm , 9.5 mm - 4.75 mm).

The six samples from each weathering grade of material were tested in accordance with NZS 4407: 1991, Test 3.14 *Broken Face Test*. A broken face is required to be fresh and cover two or more of the surfaces of the rock fragment and these rock fragments must amount to more than 70% of the test sample in each fraction.

The draft NZTA M/4 specification states that the broken face content of each sieve size above 4.75mm shall not be less than 70% by weight, and shall continue to have two or more broken faces on each rock fragment. This does not affect the compliance of the material with the draft proposed specification, as all samples showed 100% broken faces.

Results show that the samples meet the specification in 100% of the tests, which implies that the aggregate will interlock in a way which improve the structural integrity of the basecourse and ultimately the pavement. No amendments need to be made to the production process as the broken faces consistently meets the specification.

4.7 Particle Size Distribution (PSD)

4.7.1 Grading Curves

The particle size distribution (PSD) averages, shown in Figure 4.33, include data from 2003 to 2015. The grading of the basecourse was within the specified limits through the study period, with most of the grading curves tending toward the finer fraction (minimum line). In 2008, the 26.5mm fraction started being recorded, for reporting purposes only, but because it is not specified in the TNZ M/4 specifications, it has been excluded from the graph.

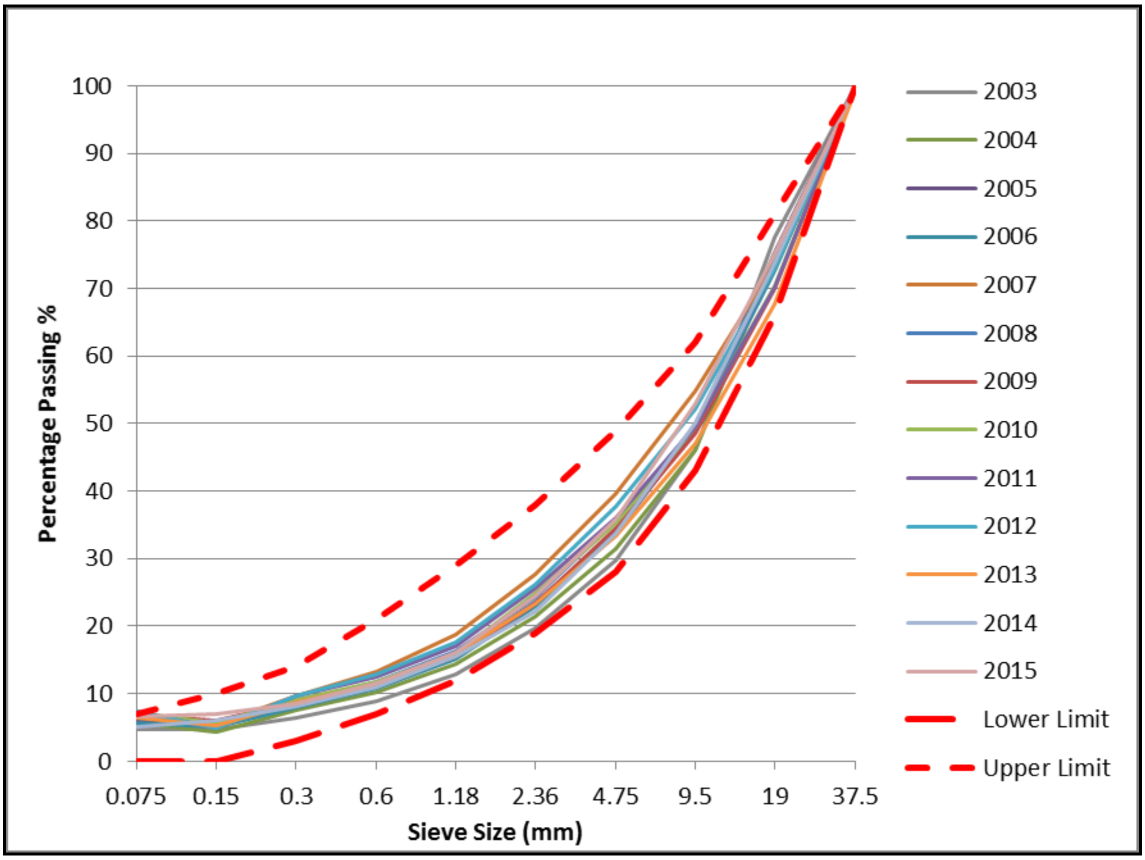

Figure 4.33 Average Particle Size Distribution for Transit AP40 aggregate samples 2003 to 2015

The averages do not accurately display the performance of the basecourse when tested for PSD. Although the material appears to have performed consistently, it has at times failed to meet the specification with either too coarse or too fine gradings;

Figure 4.34 demonstrates that results for 2003 and 2004 often fall out of the defined ranges. In 2003 the gradings were both too fine in the coarse fraction and some too coarse in the finer fraction, explaining why the average is brought within the envelope, whereas in 2004 the gradings were often too coarse in the middle fractions, with only some of the gradings being too fine. In 2004 and 2005 (results not displayed) over sixty tests were performed; this would seem excessive, requiring more than one test per week, and it is assumed that this may be the result of repeat testing. When a sample falls short of the required specifications, adjustments to the processing plant are conducted and/or sampling and retesting follows.

In 2006, blending inline hoppers were introduced, which allowed for a more efficient system of adding fines. This, coupled with a management and process change in 2007, resulted in a basecourse which performed better by consistently passing the requirements (Figure 4.34). The PSD from 2007 shows that most of the gradings fell within the envelope, and there was little variance between the samples. This has remained consistent through the study period, as can be seen from the 2015 PSD data.

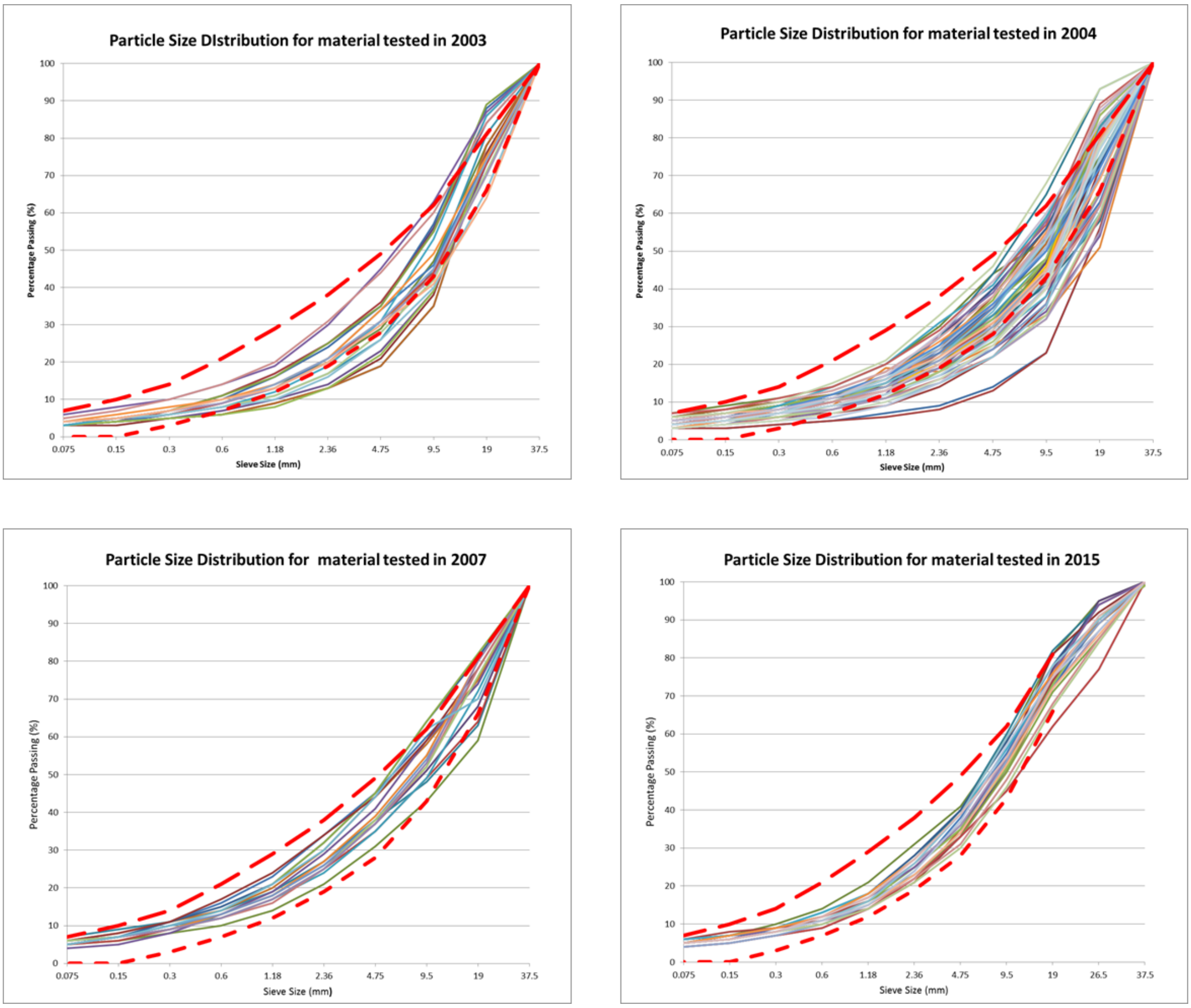

Figure 4.34 Particle Size Distribution recorded for 2003, 2004, 2007, and 2015. Red dashed line indicates the grading envelope (upper and lower limit for each fraction size). Solid lines represent results for individual samples

Six samples from each of the three weathering grades of material (T-Grade, C-Grade and G-Grade) were prepared and tested at the PLQ laboratory in accordance with NZS 4407: 1991, Test 3.8.1 *Wet Sieving Test*. The grading slopes of all 18 samples fell within the specified envelope, of the current M/4 specification (Figure 4.35). The gradings generally fall in the centre of the envelope with the middle fractions (1.18mm -4.75mm) falling to the finer fraction. The coarser fractions have a tighter envelope and generally fall toward the coarser side (maximum limit line).

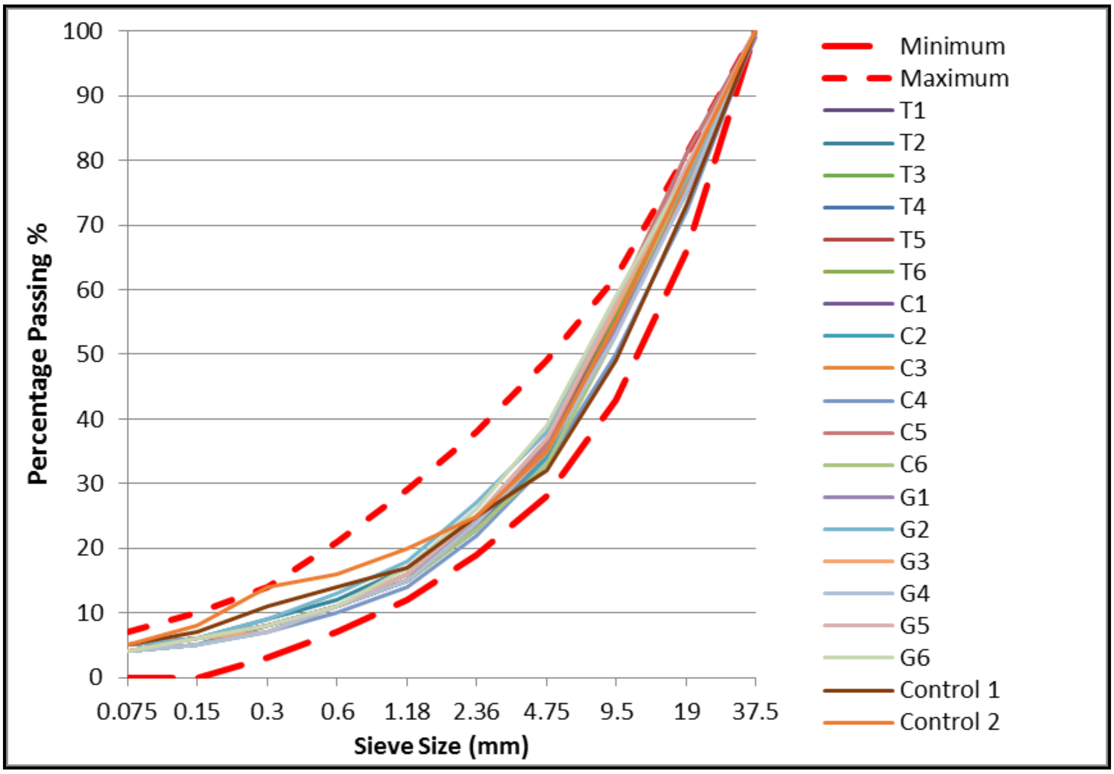

Figure 4.35 Particle Size Distribution values for T-Grade (T), C-Grade (C) and G-Grade (G) graded aggregate samples, tested in accordance with the current TNZ M/4 specification.

The current test method does not differ from the proposed draft TNZ M/4 specifications, but the draft TNZ M/4 specification requires a reduced maximum value for PSD compliance resulting in a tighter envelope. There are only minor adjustments in the proposed draft specifications, but these still make an impact, as they allow for less coarse material (Figure 4.36). As previously mentioned, the material falls toward the maximum line in the coarser fractions and crosses over this upper envelope with the draft specification. The only fraction in which the samples did not satisfy the draft envelope was the 9.5mm fraction. Five (T6, C5, G2, G5, G6) of the 18 samples fell above the maximum limit of 57 with G6 falling 2% above this limit and the rest only 1% above. In the other coarser fractions some samples were on the limit line but did not exceed this.

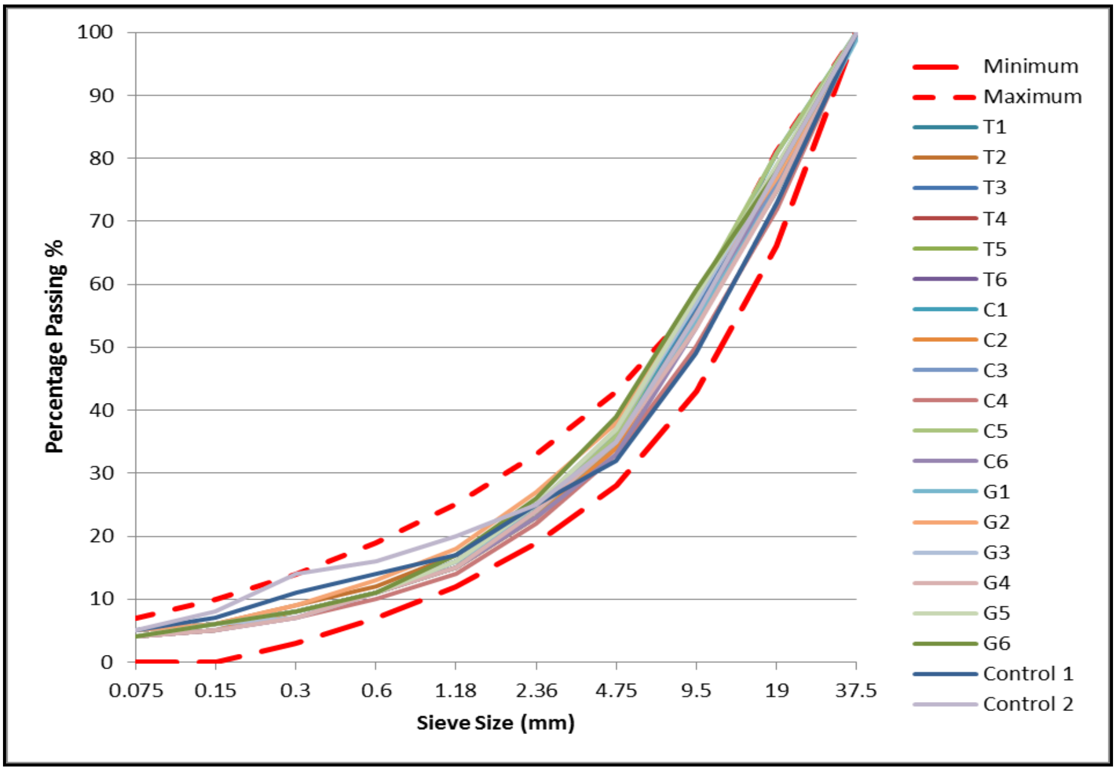

Figure 4.36 Particle Size Distribution values for T-Grade (T), C-Grade (C) and G-Grade (G) graded aggregate samples, tested in accordance with the draft TNZ M/4 specification

The historic data shows that at times the PSD has not always met the specification and changes were made to the production process to get the aggregate to fall within the envelope. After the problem was rectified the material has consistently met the specification. The research samples were collected without the addition of the Barmac crusher fines and they continued to meet the grading. This is not to say that the Barmac crusher fines should be eliminated from future production. With changes in the rock from differing parts of the quarry it may be necessary to include these fines. Further investigation would need to be conducted to determine if the Barmac crusher fines are still necessary. If the rock characteristics vary from different areas of the quarry then the addition may prove essential to meeting the standard.

4.7.2 Grading Shape Control

The particle size distribution grading shape control, which changed in the proposed draft specification to allow for incremental grading shape (IGS) control, calculates the Talbot's n-value between given sieve sizes and must range between 1.0 and 0.3 to pass the specification.

An average value for the samples from each of the three weathering grades of aggregate (T-Grade, C-Grade and G-Grade) was obtained, with all falling well within the limit range (Table 4.1). The lowest average value was 0.53 and the highest was 0.57, indicating very little variance between the 18 samples.

Table 4.1 The average incremental grading shape (IGS) values for the samples of Transit (T), C-Grade (C) and G-Grade(G) material; values averaged from the six sieve ranges.

Sample Id	IGS	Sample	IGS	Sample	IGS
T1	0.55	C1	0.57	G1	0.53
T2	0.53	**C2**	0.56	**G2**	0.53
T3	0.54	**C3**	0.54	**G3**	0.56
T4	0.53	**C4**	0.56	**G4**	0.57
T5	0.54	**C5**	0.55	**G5**	0.55
T6	0.55	**C6**	0.57	**G6**	0.55

An average for each sieve range was calculated, which included the data from the three weathering grades of aggregate, to identify any areas of concern (Table 4.2). The lowest value was 0.48 for the 600 µm to the 150 µm fraction and the highest was 0.60 for the 9.5 mm – 2.36 mm fraction. These results indicate that if the test was to be included, as proposed in the draft TNZ M/4 specification, the PLQ aggregate should consistently meet this specification.

Table 4.2 Average grading shape control values for each sieve range from the three weathering grades of aggregate (Transit, C-Grade and G-Grade)

Sieve range	Average IGS
19 mm – 4.75 mm	0.56
9.5 mm – 2.36 mm	0.60
4.75 mm – 1.18 mm	0.59
2.36 mm – 600 µm	0.57
1.18 mm – 300 µm	0.50
600 µm – 150 µm	0.48

When investigating the historic data for TNZ M/4 AP40 aggregate from 2003 to 2015, only the 19. 5mm- 4.75 mm fraction in 2003 failed to fall within the specified envelope, and the average value for that fraction was 1.01, which is only 0.01 above the permitted maximum of 1.0 (Figure 4.37). The samples which contributed to this failure passed the specification for the other ranges, and therefore had a combined average which fell within the specification. In 2005, the result for one sample fell below the minimum of 0.3 in the smallest fraction (600 nm -150 nm) and had a value of 0.17. In recent years, all samples passed the specification in all sieve ranges.

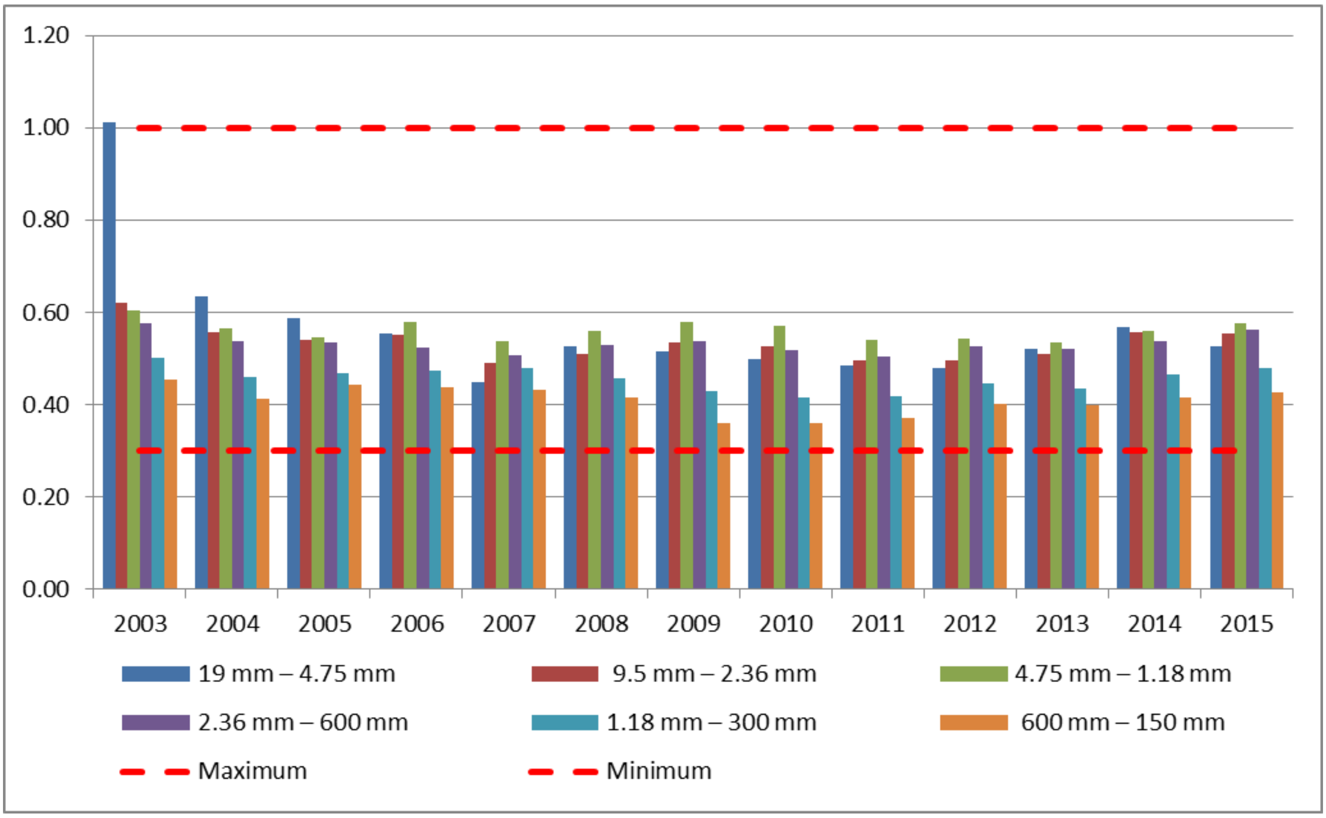

Figure 4.37 The average grading shape control values for M/4 AP40 aggregate for each sieve range and for each year from 2003 to 2005. The red dashed lines indicate the maximum and minimum envelope for compliance

The historic data shows that at times the PSD has not always met the specification and changes were made to the production process to get the aggregate to fall within the envelope. After the problem was rectified the material has consistently met the specification. The research samples were collected without the addition of the Barmac crusher fines and they continued to meet the grading. This is not to say that the Barmac crusher fines should be eliminated from future production. With changes in the rock from differing parts of the quarry it may be necessary to include these fines. Further investigation needed to determine if the Barmac crusher fines are still necessary. If the rock characteristics vary from different parts of the quarry, then the addition may prove essential to meeting the standard.

The introduction of the new calculation for the grading shape control would not negatively impact the aggregate in meeting the specification. The calculations were conducted for all results, both historic and those samples collected for this research. It was found that at times in 2011 44% of the samples failed to meet the control envelope, but this has increased considerably whereby in 2015 only 8% of the samples failed. These samples failed because of the finer fraction size (which takes into account the values form the 1.18 mm and 0.15 mm sieve), as was the case for most samples which didn't meet the criteria.

4.8 Summary of M/4 Specifications

All Source Property testing in the past has consistently met the standard with only some failures noted in the historic results for the Weathering Quality Index result. The crushing resistance generally ranged between 4 – 6 % for all sets of data. The WQI for the historic data had a majority of results in the BB grouping, and BA for this research data set. All of the results for the CBR were well above the minimum limit of 80%. There were no amendments included in the draft specification for the source property testing. All of the control stone results met the source property requirements

Production Property testing showed some variability. The Sand Equivalent met the specification on average over the years, but some isolated failures on individual samples were recorded. The samples tested in this research had one failure in the G-Grade data set, and both the control stone values did not pass the specification, however all other samples passed. The CI and PI are particularly notable as the material consistently failed the CI test, with no results falling below the specified limit of 3 for the historic data set, the samples tested for this research. The weight CI in the draft specification had 1 sample out of the 18 tested that passed. The PI results did not meet the specification (on average) from 2010 onwards and from 2014 the PI has remained above the limit of 5. This can be attributed to variations within the quarry or the competency of the technicians. All samples tested for this research were non-plastic for both the current and draft specification. Broken faces and PSD indicate no remarkable mentions as the results fall well within the specified limits, in the past the PSD had some failures but this has been controlled. The addition of the Sand Grading Exponent in the draft specification would require a sample to pass three of the four tests (SE, PI, CI, and SGE). PLQ aggregate consistently met the SGE, included into the draft specification, and therefore would still be classed as suitable aggregate as long as the PI remained below the limit of five.

From these results it is evident that quality of fines needs more investigation. The Clay Index consistently failed except for one result in the Weighted CI values. From the literature it indicates the CI value might not be as representative of deleterious clays as thought in the industry. It type of clays need to be identified to determine if they are deleterious and may cause aggregate breakdown overtime. The PI values were very variable and inconsistent as discussed this may be the result of variability in the quarry or the competency of the technician conducting the test. The clay content is known to vary and could be the influencing factor in the PI results, different clay types are likely to result in different PI values as kaolinite clay minerals are generally non-plastic whereas smectite clay minerals can result in very high PI values. . Further investigation needs to be conducted to accurately identify the variability, clay analysis was conducted and the results from this research can be found in Chapter 5. Additional investigations should include interlab testing and recording where in the quarry the material was extract from to determine any correlations.

5. Chapter Five: Evaluating Additional Material Tests

5.1 Introduction

Following from the specification analysis it was identified that the Clay Index and Plasticity Index test results needed further investigation to understand the quantity of clays present and variability of the plasticity index. Therefore, additional test were conducted on the PLQ aggregate to determine or confirm other characteristics of the material. These tests that have been used, or are being developed within the industry, but are not yet part of the standard testing regime. The results of the analysis conducted can be found in Table 5.1. Following this extended investigation, a summary of how these tests and those in the specifications affect the pavement performance are discussed.

Table 5.1 Results from analysis conducted for the evaluation of additional test methods.

Test	Results	Comments
NZTA T20 Accelerated Weathering Ethylene Glycol test	All samples including greywacke control stone had a change above the proposed limit of 30	Test method change significantly during this research
Indirect Tensile Strength	1% proved the most favourable cement concentration for stabilising material	The required strength was targeted at 400kPa
Indirect Tensile Strength EG soaked	All samples had a significant decrease in strength after soaking in EG and the stabilising with 1% cement	The test was deemed
Thin Sections	Alteration was evident in all samples	
X-ray Diffraction	No significant expansive clays were found. Majority of clays were Halloysite	Other minerals included albite and augite
Scanning Electron Microscopy	Alteration evident in all samples. No clays were identified	
Failure Plane Analysis	Faults and joint sets evident from face mapping. Hand samples indicated open fractures swelling to elongated vesicles. Fracturing on a micro scale around mineral boundaries and within minerals.	Stresses induced after cooling and mineralisation.

5.2 Accelerated Weathering Test: Ethylene Glycol

This test is conducted according to the NZTA in-house materials testing document which states that the method is similar to that of NZS 4407:1994 Test 3.10, *The Crushing Resistance Test,* but includes an additional process of soaking the material in ethylene glycol for 21 days (NZTA, 2015.).

The method was based on a test developed in South Africa from 15 years of research on basalts and dolerites in that country (Leyland, et al. 2014).

The South African test requires 40 pieces of rock (13-19mm) to be placed separately into ethylene glycol and observed over 20 days during which the stones will disintegrate. The results of this disintegration is rated according to a formula derived by Leyland, et al. to determine the modified ethylene glycol durability index (mEGFDI). The authors decided that the test was suitable for identifying material with poor durability, but was inconsistent with existing specifications. Therefore the authors proposed that the material be further assessed for effects of the ethylene glycol soaking using the 10 percent Fines Aggregate Crushing Value (10% FACT) test (S.A. Bureau of Standards, 1976), which is based on the same principles as the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.

The procedure followed in the present research is described in detail here. The preparation of the samples follows the crushing resistance test procedure, where approximately 3 kg of material between 9.5 mm -13.2 mm is retained and washed. The sample is then soaked and fully covered in ethylene glycol for 21 days and left undisturbed. After 21 days, the sample is drained and placed in an outside (exterior to a building) oven to allow the ethylene glycol to evaporate. An outside oven was required for safety reasons. After two days in the oven at 80°C, the sample is weighed at four-hour intervals until the difference between weighings is less than 0.1%. From this point, the method continues to follow test 3.10 but includes re-sieving on the 9.5 mm sieve; this was not specified in the test method, but was necessary to follow the Crushing Resistance test method.

The sample is then placed into the cylindrical mould in three lifts and tamped with a rod twenty-five times at each interval. The sample is subjected to increased loading, which must achieve 130kN within 10 minutes. The fines of the material passing the 2.36 mm sieve are recorded and a percentage calculated. This is then compared to a crushing resistance of the same material which has exactly followed NZS 4407:1994 Test 3.10, *The Crushing Resistance Test,* and undergone no additional soaking. The result is calculated by the following equation (Equation 2);

$$\text{Compliance Factor} = \frac{(y-x)}{k}$$

y = Percentage of material passing the 2.36 mm sieve from the soaked sample

x = Percentage of material passing the 2.36 mm sieve from the un-soaked sample

$$k = \frac{20}{y}$$

It is not known where the constant value of 20 is derived from. A value great than 0.5 is considered a failure.

The samples were wet sieved at the PLQ laboratory and cleaned and tested at the Christchurch laboratory. The results for these test can be found in Appendix J. Three samples were not tested (T2, G2, G4). Only two samples did not comply (T5, G3). The negative values represented in Figure 5.1, for samples T1, C and C5, are to be reported as “no change”; they are displayed to indicate that such values are possible. This occurs when the soaked crushing resistance has a lower value than the unsoaked crushing resistance displayed in Figure 5.1, with usually little variance between the two results (unsoaked and soaked). The greywacke control stone was tested using the method described and passed the test with one having no change.

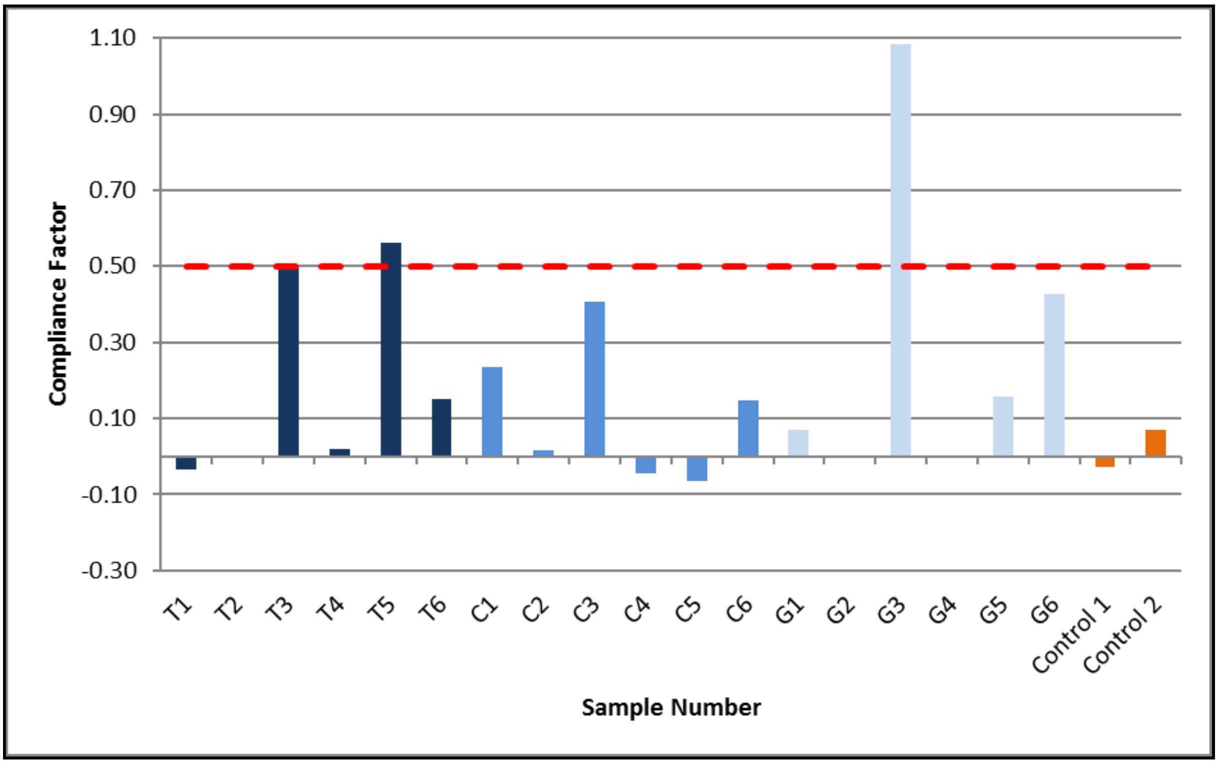

Figure 5.1 The Accelerated Weathering test results for the 18 samples collected from the three weathering grades of aggregate; T-Grade, C-Grade, G-Grade and Control sample basecourse aggregate. T = T-Grade C = C-Grade, G =G-Grade. The red dashed line indicates the maximum allowable Compliance Factor of 0.5.

The highest value recorded was for sample G3 with a compliance factor of 1.1, and the lowest value was -0.1; data for all three samples, (T1, C4 and C5) are to be reported as ‘no change’.

Figure 5.2 shows the same samples with their values expressed as a crushing resistance percentage without the Compliance Factor taken into consideration. If the Compliance Factor was factored in, then all the samples would pass the Crushing Resistance test. The red dashed line indicates the maximum allowable percent of fines for the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test.* This included to indicate that all sample would pass the Crushing resistance test at 130kN, but is not the specification for this particular method.

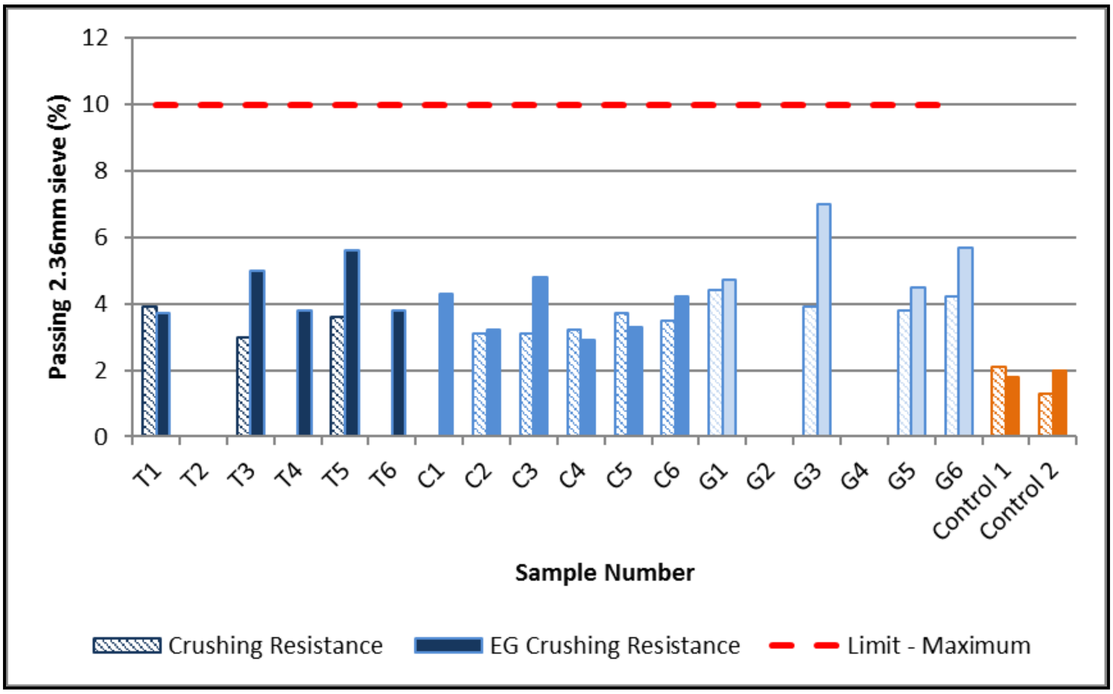

Figure 5.2 Crushing Resistance and Ethylene Glycol Crushing Resistance values for samples of the three weathering grades of aggregate; T-Grade, C-Grade, G-Grade and Control sample basecourse aggregate. T = T-Grade C = C-Grade, G =G-Grade. These values were used to calculate the results for the Accelerated Weathering test

It can be observed that the soaked Crushing Resistance percentage has a greater influence on the Compliance Factor than the unsoaked Crushing Resistance result. The results varied, with some samples not meeting the requirement, while others indicated that the soaked material was more durable than the unsoaked. There was a slight trend with weathering and durability, where the more weathered the rock was the greater the control factor was indicating durability susceptibility. This was more evident in when looking at the fines passing results (Figure 5.2), but when looking at the compliance factor results the trend was less obvious. This range of results between samples and between grades emphasises the need for further investigation into the test method and its outcomes.

Similarly, Bell & Jermy, (2000) conducted ethylene glycol (EG) soaking tests on cores extracted from diorite sources in South Africa. The results indicate that samples from the same source had differing responses when exposed to EG, with some having little to no response at all and others being classified as rapidly weathering diorites. This was attributed to the permeability of the rock and subsequent internal exposure to EG; the more EG can penetrate the sample the more likely it will break down if deleterious minerals are present.

After the testing was completed as a part of this research, the author of the Accelerated Weathering Test was contacted for further information as the test included some ambiguities. It was found that the method had been rewritten twice and amendments had not been published. The calculation used to determine the result was also removed and instead a percentage change was used (Figure 5.3). This shows a larger variability within the results, and that the control stone (which is known to be good quality aggregate) would fail if the suggested limit of 25% was used. Ultimately the acceptance criteria would have to be above 60% for the sample to pass, but then this would potentially allow poor aggregate being passed as good aggregate. This shows the effect of having a large percentage change over a small grading value. After consultation with others in the industry it was found that the method being followed was as used in this research. Although the results may not be comparable with other Accelerated Weathering test due to the ambiguity in the method, they are comparable within themselves as testing was conducted consistently in the same manner every time.

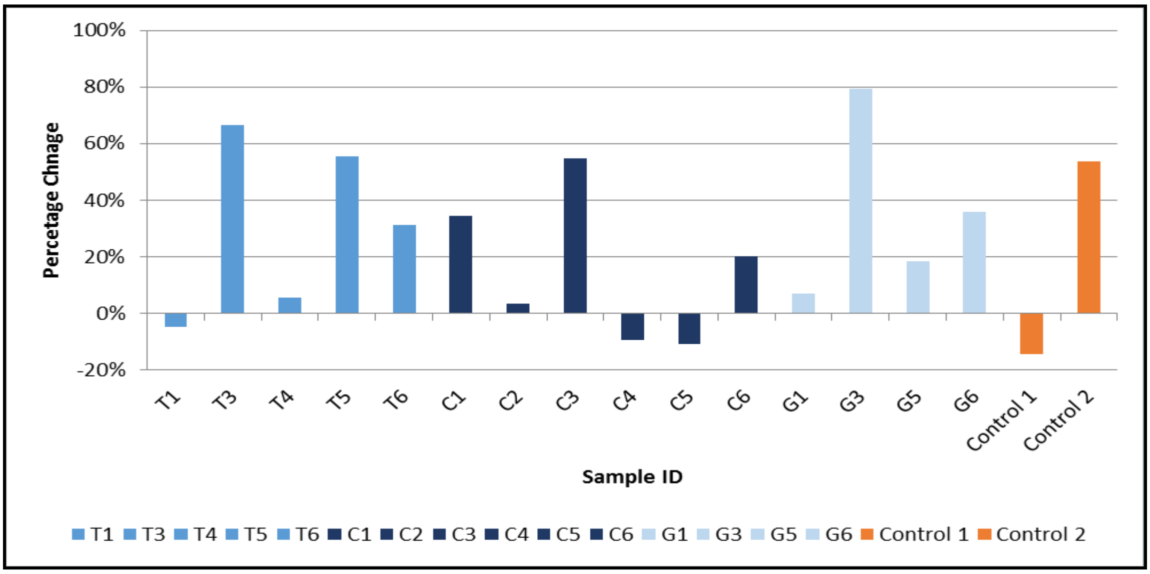

Figure 5.3 Accelerated Weathering test results displayed in the newly advised method of calculation which takes into account the percentage change between the soaked and unsoaked crushing resistance. Note how the control stone value differ considerably and highlights the results when there is a change over a small number.

This information was passed on to the authors of the test method and further amendments were included. The test named NZTA T20 - Ethylene Glycol Accelerated Weathering Test was refined and amended in the in the following ways:

1. The test would be conducted on 4 samples.
2. Two samples would be subjected to 21 days of soaking in ethylene glycol and the other two would be used as controls, and not soaked. The samples must be within 10g of one another.
3. On completion of soaking the samples are drained passing the liquid over a 75 µm sieve with a 2.36mm sieve as a protection.
4. Place all material retained on the sieves onto a drying try. Water can be used to wash all fines into the tray. The sample is dried until saturated surface dry condition is reached, within 48 hours.
5. The sample is then subjected to a 230kN load, which differs from the 130kN load in the previous versions of the test. The test specimen is then dried in an outside, vented oven not exceeding 90°C for 24 hours. The finally drying is done in a 110°C oven.
6. The fines passing the 2.36mm sieve are recorded and the averaged for the 2 specimens.

The control samples are tested the same as the previous versions but instead are subjected to a load of 230kN. The fines passing the 2.36mm sieve are recorded and then averaged for the two specimens.

A percentage change from the averaged control samples to the averaged soaked samples is determined.

This method was tested on material collected for this research and additional material that was sampled on the 29 July 2016 and the reports for these tests can be found in Appendix J. This was conducted to allow for multiple tests using the new NZTA T20 method. The additional material was collected from three different stockpile pads. Each pad was created from the same stockpile source.

Figure 5.4 shows the percentage change for each sample. The results indicate that for a target of 30% all five samples would fail. At the time of writing the target limit had not been decided but the limit of 30% had been referred to. The Pad B sample performed the worst with a percent change of 82%. Pad C and the Control stone were 47% and 40% respectively. For the same material there is a large variance in the results even though the test is repeatable. This indicates that there is little significant difference between these two samples. The Canterbury greywacke had both the control samples and soaked samples crushing resistance values at 230kN below 10%. This should indicate a highly durable stone, but the test suggests otherwise.

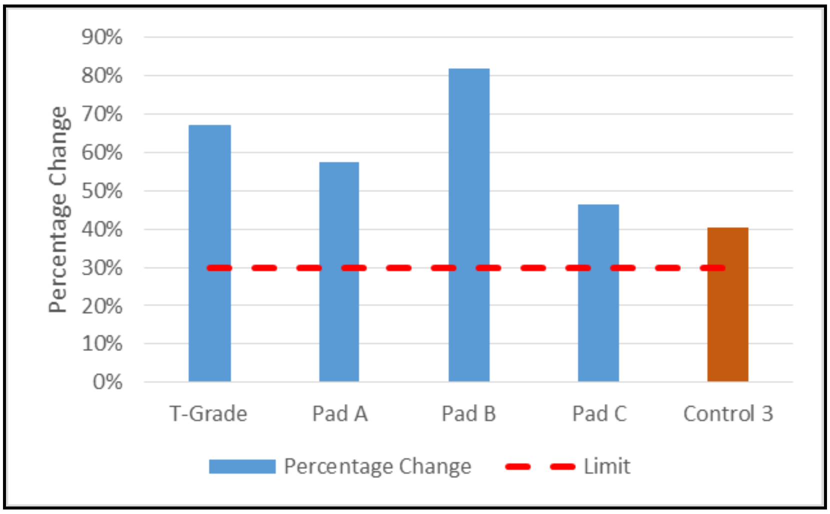

Figure 5.4 Percentage change values for the NZTA T20 Accelerated Weathering Ethylene Glycol test. The red dashed line indicates the maximum limit of 30%

As a result from this research more work and investigation needs to be conducted before the test is published and incorporated into routine testing for aggregate. It is also important to gain a proper understanding of how New Zealand aggregate reacts to ethylene glycol. The test results may be influenced by the increased pore pressure within the rock and not by the clay content. Clay analysis was conducted on all the samples and the results are discussed in the X-Ray Diffraction section 5.2.2.

Smectite clays are not the only expansive clay, but with this knowledge and the variable results from this research it can be concluded that a more thorough and accurate test method needs to be developed which is backed by extensive research and data on how effective the test is in relation to

New Zealand aggregate sources. During this research the availability of 99% ethylene glycol was limited and international suppliers were contacted, but not needed. The supply issue will need to be addressed, as the demand for 99% ethylene glycol is bound to increase if the method is included into current testing regimes. Not only will the initial demand be increased but currently no recycling, reusing or disposing processes are in place. This would likely mean that the EG would need to be disposed and a fresh supply be used for each test.

5.3 Indirect Tensile Strength (ITS)

The ITS testing was conducted in accordance with the draft NZTA T/19 and the test method used can be found in Appendix D. The ITS testing was conducted to determine is stabilising the aggregate with cement would allow for a strong basecourse and illuminate any effect from the clay content. The ITS tests were initially conducted on the C-Grade material to determine the appropriate cement percentage. The samples were all from the same source and stockpile as outline in chapter 3.4.5. Once the correct concentration of cement was determined, testing was conducted on T-Grade, C-Grade and PLQ Transit M/4 basecourse with added Barmac crusher fines material. C-Grade samples were tested first; samples were corrected to 6% moisture, and the cement was added in concentrations of 1%, 1.5% and 2% (Figure 5.5). The average ITS for the C-Grade aggregate with 1% cement was 338 kPa, with 1.5% cement was 621kPa, and with 2% was 475 kPa.

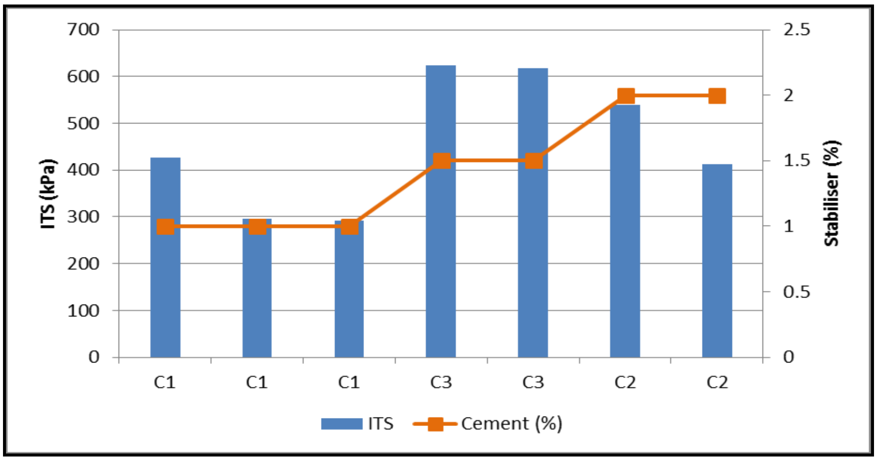

Figure 5.5 Indirect Tensile Strength (ITS) results for C-Grade aggregate samples stabilised with varying cement concentrations.

A target ITS value of 400 kPa is considered a desirable strength that aids stabilisation. The results from the tests indicated that the 1% cement yielded the most favourable result and therefore was selected as the stabiliser percentage for further testing. The test reports can be found in Appendix J. Subsequent testing was conducted on T-Grade material and PLQ TNZ M/4. The PLQ M/4 is traditionally produced from the T-Grade rock with the addition of Barmac crusher fines, added to improve the PSD. Fines material are added to achieve the grading and are generally 4.75 mm and below. They help fill the voids created when the larger particles interlock, they provide stability and overall strength for the basecourse. The samples which were produced following the traditional method with the inclusion of Barmac fines have been identified by the nomenclature of "PLQ Barmac" in Figure 5.6. The average ITS from all the PLQ samples was 392 kPa and the average for the Miners Rd samples was 351 kPa

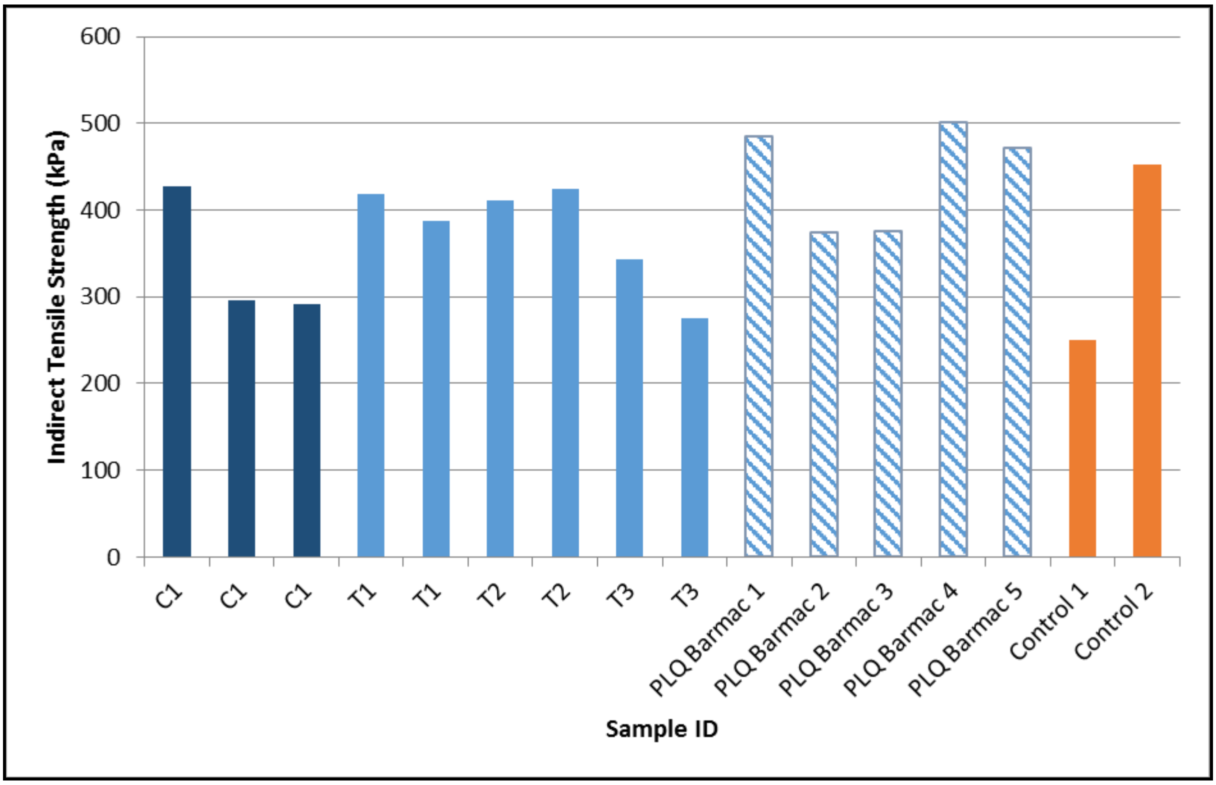

Figure 5.6 Indirect Tensile Strength (ITS) results of aggregate stabilised with 1% cement. Samples were collected from C-Grade(C), T-Grade (T), M/4 AP40 aggregate with the addition of Barmac fines (PLQ Barmac), and the control stone

ITS testing was conducted to determine how stabilisation would influence the material. This was deemed necessary because none of the results from Chapter 4 showed conclusive evidence of only one particular failure mechanism. The identified problems with the aggregate were highlighted to be the Clay Index (possible clay content), in some instances the Plasticity Index, and the fracturing throughout the rock. It was decided that if the material was structurally sound and bound together with cement it would prove beneficial for the aggregate durability as this would not allow the aggregate to breakdown further.

The results of the ITS testing indicated that 1% is the most suitable cement concentration for the aggregate mix. The average result from all of the ITS testing at 1% cement indicating a promising strength of 392 kPa. The low concentration of cement needed for the stabilising allows for a more economic product without changing the other pavement properties. The stiffness change of a pavement with 1% cement is considered negligible when designing. If stabilisation can be achieved on site (at the quarry) with use of a Cement Treated Basecourse (CTB) plant than an effective and efficient product can be produced.

5.4 Indirect Tensile Strength (ITS): Soaked in Ethylene Glycol

Following the determination of the most suitable percentage of cement stabiliser for addition, it was deemed important to investigate the ITS of aggregate samples that had been soaked in ethylene glycol. Soaking the material in EG it would allow the clays to activate and the cement should react with the clays and allow the aggregate to perform. This was conducted to investigate if the durability of the aggregate would be compromised when soaked in ethylene glycol before stabilising and determine the effect of moisture on the aggregate. It was also conducted to determine if the EG accelerated weathering test was reliable, and how would the aggregate respond after any expansive clays had been activated. This is not standard practice and no method has previously been devised for this, and it is unlikely that this will be included into current testing regimes as the method was devised during this research for investigation purposes only. The ITS testing was conducted in accordance with the draft NZTA T/19 and a summarised test method can be found in Appendix D and test reports can be found in Appendix J. The material was soaked in ethylene glycol for 21 days prior to testing. The samples included PLQ Transit AP40 without Barmac fines, PLQ Transit AP40 with Barmac fines, and Miners Rd Transit AP40. The Miners Rd material was used as a control stone and is regarded as a premium aggregate. On completion of the soaking it was drained of any excess liquid and placed in an 80°C oven to dry. The drying process took substantially longer than for the Accelerated Weathering test. Due to limited oven space in the laboratory the trays were dried in the oven over two consecutive weekends (five nights in total), until the mass recorded within 0.1% between weighings. The samples were corrected for moisture content and then prepared in accordance with the test method. The average ITS for the PLQ Transit AP40 material was 125kPa compared with 142kPa for the Miners Road quarry material (Figure 5.7).

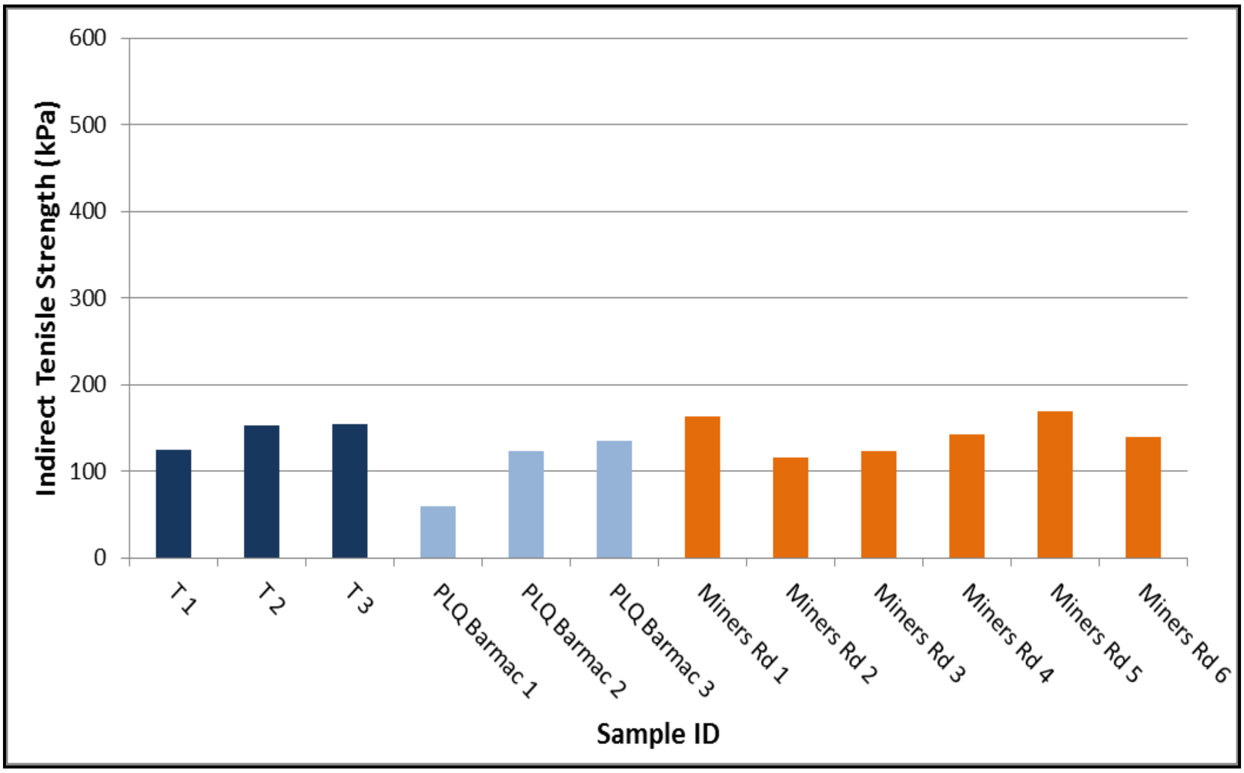

Figure 5.7 Indirect Tensile Strength results from aggregate soaked in Ethylene Glycol for 21days and then stabilised with 1% cement. Samples tested were PLQ M/4AP40 aggregate with and without Barmac fines, and the Miners Rd control stone.

The ITS of the ethylene glycol soaked material is markedly lower than that of the unsoaked material.

The PLQ Transit AP40 aggregate that included the Barmac crusher fines had the lowest average ITS of 106 kN, while the Miners Rd control stone had an average ITS of 142 kN and PLQ Transit AP40 aggregate without Barmac crusher fines had an average ITS of 144 kN.

The samples soaked in EG before testing displayed a decrease in strength; the average soaked PLQ material was 125 kPa which is a 68% decrease. The Miners Road material averaged at 142 kPa which was a 60% decrease. This shows that even with an aggregate which has performed consistently well over the years and shows no sign of premature degradation, it will still show a significant decrease in ITS when exposed to EG before the samples are prepared for testing. The samples were moisture corrected to ensure comparable result but it was found that the moisture content was above optimum and may have been related to the EG soaking. The EG would have infiltrated the matrix of the sample and filled any fractures and open spaces. The evaporation process may have been so slow (because the matrix was saturated and not only the surface) that the sample was deemed effectively dry. When then conducting a moisture correction too much water was added as none of it could infiltrate the matrix of the rock as this was already occupied by the Ethylene Glycol.

5.5 Smectite Identification in Crushed Material

The smectite clay identification technique was developed for field application and the method can be found in Appendix D. It was conducted on the PLQ AP40 material to determine if the test produces different results when compared with the CI test; both methods are similar, with the main difference being the size of the sieve. The CI test method tests for material passing a 75 µm sieve and this smectite identification tests for material passing a 125 µm sieve. It is assumed this is to allow for rapid testing in the field, where it is easier to gather the slightly larger particle size. At the time of testing no 125 µm sieve was available and a 150 µm sieve was chosen, because the test was developed for in-field application and a stricter limit of the fraction passing through was deemed to be acceptable. The test was repeated with each sample and results are shown in Table 5.2.

Table 5.2 Smectite concentrations determined using methylene blue. Percentage values are averaged from the two test samples

Sample Material Type	G-Grade		T- Grade		C-Grade	
Number of Drops (ml)	7	7	6	6	4	4
Percentage of Smectite Clay (%)	7 %		6%		4%	

The G-Grade material contained the highest concentration of smectite clays, if the test does identify slay type, with the C-Grade material having the lowest. The CI test revealed average indices of 4.7, 5.3 and 6.1 for the T-Grade, C-Grade and G-Grade material respectively. The results were so similar for both the smectite identification and the CI test, it was decided that testing all samples using this method was unnecessary for clay type identification. Neither method specifically identifies for clay type but rather clay content.

The additional method, slightly differing from the CI method, was conducted to determine if there was a significant difference between this test and the CI test. It was found that the results varied very little from the original CI method and therefore was not continued with for all subsequent samples. It was also deduced that the test could not specifically test for smectite as previously discussed (see 6.3.1.2 Clay Index) because of how the methylene blue reacts with many types of clay and other minerals under certain conditions. The author of this research assumed that this method was labelled for smectite identification because it was pre-determined what the clay mineral within the aggregate source was.

5.6 Mineralogy Analysis

5.6.1 Methodology

The methods used to determine and confirm the mineralogy of PLQ, and any susceptibility to alteration and the formation of deleterious minerals, were thin sections and microscopy, X-ray diffraction analysis, and Scanning Electron Microscopy. Evidence of clays was of particular concern, and was focused on extensively. This is because expansive clays can increase in volume causing additional stress within the aggregate, which may compromise the durability of the rock and cause the material to break down.

5.6.2 Thin Sections

At PLQ hand samples were collected at the base of the freshly excavated face, and from the stock piles after processing through the Primary Crushing Plant. These samples were categorised as 'before crushing' and 'after crushing' based on when and where they were collected. This was conducted to determine if the crushing process had any effect on the micro-veins and fractures within the rock. This was not used to differentiate between any changes in the mineralogy as it was expected that the crushing process would not alter this. Thin sections were prepared at the University of Canterbury. The specimens were cut into usable pieces using a diamond saw. Each sample was approximately 10 mm x 40 mm x 20mm. These were then glued using araldite and polished at the University of Canterbury onto glass, to create a thin section slide. The thin sections were examined using a Leica DM EP microscope at between 4x and 20x magnification in Plane and Polarised Light. The mineralogy and textures were determined and summarised in the table below. Details from all the thin section observations are included in Appendix K.

When preparing the samples, the rock would often break along the micro-veins, making it difficult to capture the larger micro-veins in the thin section. This was overcome by cutting the rock slowly, ensuring the open fracture was not too close to the edge of the sample.

The thin sections indicated that within the quarried face there was rock of different colours but no compositional difference. The colours ranged from a grey blue colour to a red brown; this was found throughout all three weathering grades of material, but was not obviously visible when looking at the face. The thin sections confirmed the mineralogy of the aggregate showed no major differences between the three weathering grades. The common minerals among all three were the feldspars, both potassium rich (K-feldspar) and plagioclase feldspar, and the pyroxenes (clinopyroxene and orthopyroxene). These four (K-feldspar, plagioclase, clinopyroxene and othropyroxene) minerals made up the majority of the porphyritic minerals within the rock. The hexagonal pyroxenes would have altered from olivine, and this process was most likely complete as no evidence of olivine were noted. When olivine alters to pyroxene it releases iron and would be the likely source for the iron oxides and staining.

Dissolution (melting back into solution) textures found within the plagioclase are likely due to the difference of the calcium and sodium rich zones. Most, if not all, of the plagioclase had zoning with dissolution textures inside the zoned edge. The zoning indicates cooling which would have occurred slowly before reaching the surface. The dissolution would have occurred after original crystallisation and indicates a more calcic mineral, which is generally more stable. This calcic-rich area is generally found on the outside rim of the mineral, with the middle being sodic-rich. The sodic rich area then underwent some type of dissolution and then recrystallised back into its mineral form. The square opaque minerals are likely to be hematite or magnetite, although no further conclusion could be drawn on this. Glass and vesicles are visible under the microscope.

5.6.3 Thin Sections - Before Crushing

Hand samples collected before crushing have evidence of fracturing throughout all three weathering grades. The fracturing appears in thin lines across the surface and at times pinch and swell to what appears to be elongated vesicles. A summary of the minerals found in the hand samples is detailed in Tables 5.3, 5.4 and 5.5. Compositions did not all add up to 100% as iron staining was evident over other minerals.

The most fracturing noticed was in the G-Grade samples, the type of fracturing can be seen in - GB-4 (Figure 5.8), which was to be expected, as the quarry rock face had the most fracturing visible, and open fractures or elongated vesicles were found in the hand samples. These were as wide as 5mm and could be seen with the naked eye. Where the fractures were not open, many were in-filled with iron rich oxides (sample TB-3; Figure 5.9), and in most cases the groundmass comprised of plagioclase and pyroxenes (sample TB-3; Figure 5.10). Glomeroporphyritic texture was seen throughout all the samples, some more extensive than others (samples TB-3 and GB-6; Figures 5.10 and 5.11).

Aphanitic ground mass was evident in all of the samples (TB-3 and CB-1; Figures 5.10 and 36). Fracturing through minerals was not common, but was found in some of the samples, indicating stress after crystallisation. Many of the phenocryst minerals had fracturing through them which indicates stress after crystallisation (samples CB-3 and CB-1; Figures 5.12 and 5.13). The in-filled fractures generally followed the boundary of the minerals. Figure 5.8 depicts the sample GB-4 and shows the dissolution of the plagioclase mineral with the zoned rim not being altered and likely to be calcic rich. Opaques are identified by their black colour in both plane and cross polarised illumination. These can be minerals, glass or vesicles. Opaques were in abundance in the matrix, and in and around the larger crystals. It is difficult to identify them further as they do not change under the microscope.

Table 5.3 Thin section petrology data for T-Grade aggregate before crushing

Source	Description	Mineralogy	Percentage	Features
T-Grade Before Crushing	micro-veins/ alteration of micro-veins, glomeroporphyritic, porphyritic, aphanitic	Groundmass	35%	microcrystalline, fine grained, hypocrystalline, elongate -plagioclase, including opaques
		Plagioclase 3-4mm	30%	euhedral -subhedral, twinned, some zoned: mostly albite
		Orthopyroxene	20%	subhedral - anhedral,
		Augite (Clinopyroxene)	10%	subhedral - anhedral,
		Glass and Opaques	7%	cubic
		Iron Oxide	5%	staining and in-filling micro veins

Table 5.4 Thin Section petrology data for G-Grade aggregate before crushing

Source	Description	Mineralogy	Percentage	Features
C-Grade Before Crushing	micro-veins/ alteration of micro-veins, glomeroporphyritic, porphyritic, aphanitic	Groundmass	40%	microcrystalline, fine grained, hypocrystalline, elongate -plagioclase, including opaques
		Plagioclase 3-4mm	30%	euhedral -subhedral, twinned, some zoned: mostly albite, including opaques
		Orthopyroxene	20%	subhedral - anhedral,
		Augite (Clinopyroxene)	12%	subhedral - anhedral,
		Glass and Opaques	8%	cubic
		Iron Oxide	5%	staining and in-filling micro veins

Table 5.5 Thin Section petrology data for C-Grade aggregate before crushing

Source	Description	Mineralogy	Percentage	Features
G-Grade After Crushing	micro-veins/ alteration of micro-veins, glomeroporphyritic, porphyritic, aphanitic Large micro-veins G-GradeG-Gradeing 2-3mm (no filling)	Groundmass	30%	microcrystalline, fine grained, hypocrystalline, elongate -plagioclase, including opaques
		Plagioclase 3-4mm	25%	euhedral -subhedral, twinned, some zoned: mostly albite
		Orthopyroxene	20%	subhedral - anhedral,
		Augite (Clinopyroxene)	10%	subhedral - anhedral,
		Glass and Opaques	10%	cubic
		Iron Oxide	8%	staining and in-filling micro veins

Figure 5.8 GB-4 sample x4 magnification in plane polarised illumination. Fracture through plagioclase mineral. Dissolution and zoning (red arrow). Large open fracture not in-filled (silver grey colour).

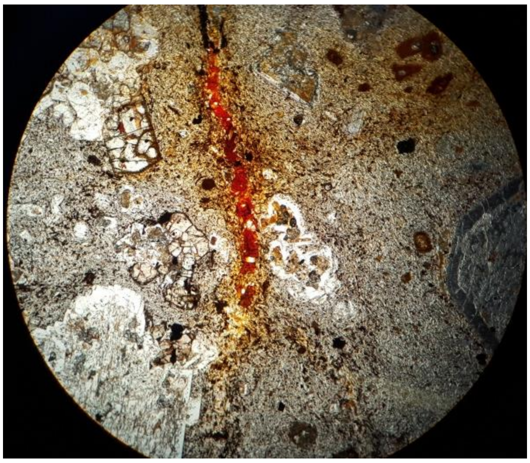

Figure 5.9 TB- 3 sample x4 magnification in plane polarised illumination. Iron oxide stain in-filling fracture.

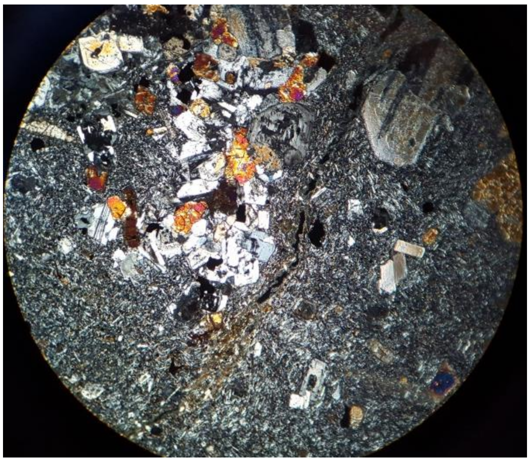

Figure 5.10 TB- 3 sample x4 magnification in cross-polarised-illumination. Micro-vein in-filled with microlite made up of plagioclase and pyroxenes, some iron staining. Glomeroporphyritic texture

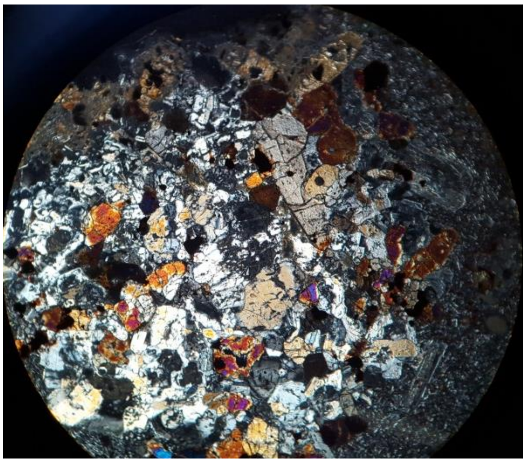

Figure 5.11 GB- 6 sample x4 magnification in cross-polarised-illumination. Glomeroporphyritic texture with the inclusion of feldspars, pyroxenes and opaques

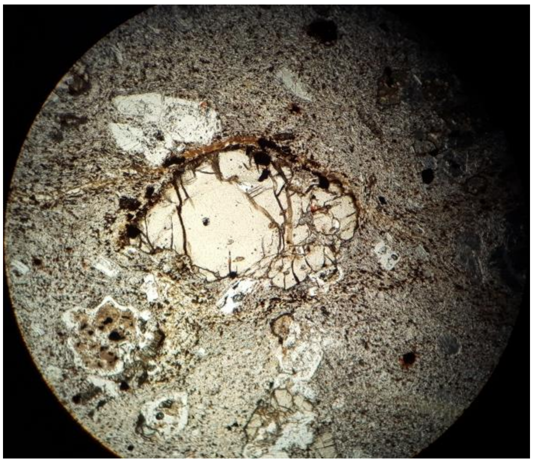

Figure 5.12 CB- 3 sample x4 magnification in plane polarised illumination. Fractured pyroxene

Figure 5.13 CB- 1 sample x4 magnification in plane polarised illumination. The plagioclase containing rock has undergone stress causing a fracture within the plagioclase (red arrow). This occurred after recrystallising.

5.6.4 Thin Sections - After Crushing

Hand samples of the crushed material were collected, and thin sections were produced from cut fragments. Similar to the samples taken before crushing, micro-veins were visible in all of the thin sections. The G-Grade samples had relatively open veins from 3 mm-5 mm in size and visible with the naked eye. Some C-Grade samples had large open micro-veins 2-3 mm, but not as wide as the G-Grade samples. A summary of the minerals found in the hand samples are detailed in Tables 5.6, 5.7 & 5.8. The compositions do not all add up to 100% as the iron staining discolouration was evident over other minerals.

As seen in the samples before crushing, micro-veins were often in-filled with iron rich minerals. Iron staining surrounding the cubic opaque minerals indicates the release of iron during alteration as illustrated in Figure 5.14 (CA-3). Parallel micro-veins with iron staining in-filling was noted in many of the samples, including in TA-5 (Figure 5.15). Intergrowth between the feldspar and plagioclase feldspar were visible; this indicates an alteration of the two minerals where the one has undergone a processes of melting or dissolution and then recrystallisation, as illustrated in Figures 5.16 and 5.17 (of samples CA-4a and b). The multiple twinning is identified in CA-4b by the appearance of longitudinal lines.

Iron staining found in sample TA-4 indicates numerous events or processes by which the composition of the solution, which precipitates out into solution and then re-crystallises, forms the iron rich bands (Figure 5.18). Either certain minerals have precipitated out from the solution until all of the mineral is no longer in solution, or the composition of the solution that is passing through from another source is changing, based on the path it follows and which minerals are dissolving in the solution. Glomeroporphyritic texture was again visible in all of the samples. Sample TA-3 in Figure 5.19 displays a large collection of minerals which, with the naked eye, could be passed off as one mineral; the minerals include plagioclase, k-feldspar, othropyroxene, clinopyroxenes, opaques and glass.

Table 5.6 Thin Section petrology result for the T-Grade rock after crushing

Source	Description	Mineralogy	Percentage	Features
T-Grade After Crushing	micro-veins/ alteration micro-veins, glomeroporphyritic, porphyritic, aphanitic	Groundmass	30%	microcrystalline, fine grained, hypocrystalline, elongate -plagioclase, including opaques
		Plagioclase 3-4mm	35%	euhedral -subhedral, twinned, some zoned: mostly albite
		Orthopyroxene	15%	subhedral - anhedral,
		Augite (Clinopyroxene)	10%	subhedral - anhedral,
		Glass and Opaques	7%	cubic
		Iron Oxide	2%	ataining

Table 5.7 Thin Section petrology result for the C-Grade rock after crushing

Source	Description	Mineralogy	Percentage	Features
C-Grade After Crushing	micro-veins/ alteration micro-veins, glomeroporphyritic, porphyritic, aphanitic. micro-vein in-filled with plagioclase	Groundmass	30%	microcrystalline, fine grained, hypocrystalline, elongate -plagioclase, including opaques
		Plagioclase 3-4mm	40%	euhedral -subhedral, twinned, some zoned: mostly albite,including opaques
		Orthopyroxene	13%	euhedral - subhedral,
		Augite (Clinopyroxene)	10%	subhedral - anhedral,
		Glass and Opaques	5%	cubic
		Iron Oxide	2%	staining

Table 5.8 Thin Section petrology result for the G-Grade rock after crushing

Source	Description	Mineralogy	Percentage	Features
G-Grade After Crushing	icro-veins/ alteration micro-veins, glomeroporphyritic, porphyritic, aphanitic. micro-vein in-filled with plagioclase. large micro-veins G-GradeG-Gradeing 2-3mm (no filling)	Groundmass	40%	microcrystalline, fine grained, hypocrystalline, elongate -plagioclase, including opaques
		Plagioclase 3-4mm	30%	euhedral -subhedral, twinned, some zoned: mostly albite,including opaques
		Orthopyroxene	10%	euhedral - subhedral,
		Augite (Clinopyroxene)	5%	subhedral - anhedral,
		Glass and Opaques	5%	cubic
		Iron Oxide	10%	Staining within the micro in-filled veins

Figure 5.14 CA-3 sample x4 magnification in plane polarised illumination. Iron oxide stain surrounding cubic opaques shown by red arrows

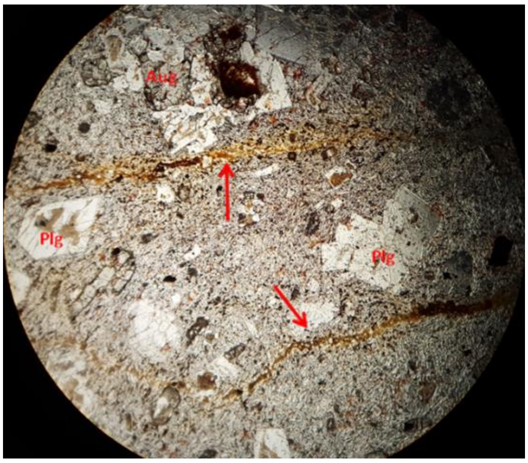

Figure 5.15 TA-5 x4 magnification in plane polarised illumination. Parallel micro veins in-filled with microlite and iron staining indicated by the arrows. Plagioclase(Plg) mineral with zoning alteration.

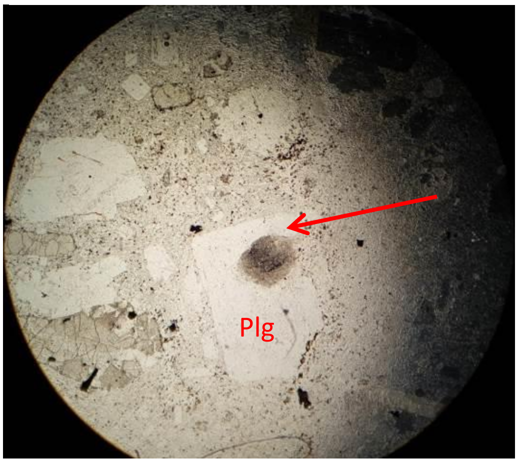

Figure 5.16 CA-4a sample x4 magnification in plane polarised illumination. Sericitic intergrowth as k-feldspar interbeds plagioclase (dirty smudge appearance indicated by arrow).

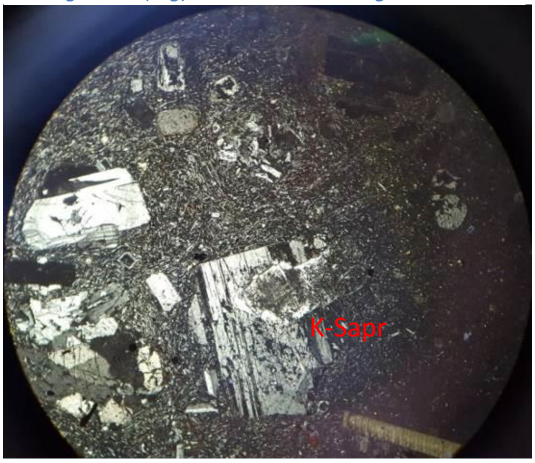

Figure 5.17 CA-4b sample x4 magnification in cross polarised illumination. Sericitic intergrowth as k-feldspar interbeds plagioclase (dirty smudge appearance). K-feldspar is more visible in XPL.

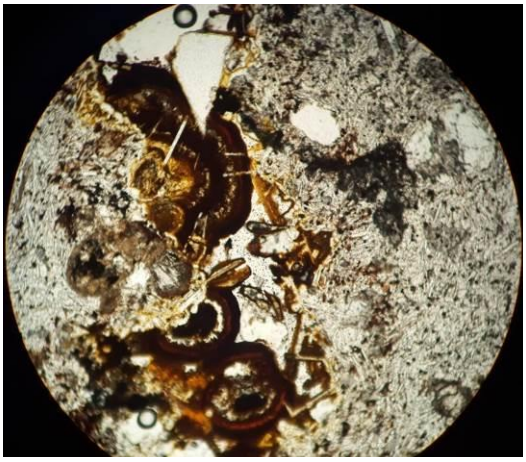

Figure 5.19 TA-4 x4 magnification in plane polarised illumination. Iron oxide stain in-filling area of dissolution and surrounding minerals. Banding indicating different precipitation events.

Figure 5.18 TA-3 sample x4 magnification in plane polarised illumination. Glomeroporphyritic texture, collection of minerals indicated by red circle.

Thin sections indicate a number of dissolution processes where minerals have undergone stress and dissolved back into solution and then recrystallised. This was often noted with the plagioclase minerals with the rim of the mineral not having undergone and dissolution but the inside showing evidence of alteration. There was also evidence of minerals altering to others, evident with the k-feldspar and plagioclase inter-growth and the olivines all altered to pyroxenes which give cause to the high iron content which would have been dropped out of solution during this mineral change.

Conditions have also changed after the crystallisation processes with evidence of fracturing forming in filled micro-veins through minerals and around the mineral grains.

5.6.5 X- Ray Diffraction (XRD)

The samples were tested in three rounds; the first two rounds (G-Grade and T-Grade respectively) had six samples each and the final round contained 8 samples (four C-Grade samples, two Miners Rd material samples and two samples from in-filling material). The 9 phi fraction was required to test the clay fraction on the XRD. The phi fraction relates to the Krumbein scale of measuring particle size. A particle size comparator can be found in Appendix M. The material was air dried and then sieved over the 53 µm sieve. The material passing the sieve was collected and approximately 15g was placed in a beaker with 20ml of deionised water. This was swirled and then poured into a 1 litre cylinder. The cylinder was filled with deionised water and stirred for 1 minute. The cylinder was covered and then left for 8 hours to determine if flocculation occurred. The sample was stirred again for 1 minute and then left for another 8 hours. Following the settling period (8 hour waiting time) approximately 30ml of the solution was poured into a beaker and left to dry in an oven at 40°C. The residue was removed from the beakers using a clean and dry wire brush and transferred to the XRD technicians in a sealed vial. Roughly 1-2g was collected for testing.

The six G-Grade samples all contained the same composition of minerals in the clay portion (Table 5.9). Two clay types were present; halloysite, a non-expansive clay, and a trace of montmorillonite, which is an expansive clay.

Table 5.9 Summarised results from X-ray diffraction from the six G-Grade (9 phi fraction) samples

Sample	Albite (%)	Halloysite Kaolin group (%)	Montmorillonite Smectite group (%)
G-Grade 1-6	90	10	trace

Data from six T-Grade samples indicate that the 9 phi fraction consists predominately of albite (45-50%), with the remaining percentage made up from augite (15-30%) and halloysite (25-30%) [Table 5.10.

Table 5.10 X-ray diffraction results from the T- Grade (9 phi fraction) samples

Sample	Albite (%)	Augite (%)	Halloysite Kaolinite group (%)
T-Grade 1	45	30	25
T-Grade 2	50	20	30
T-Grade 3	55	15	30
T-Grade 4	45	25	30
T-Grade 5	40	35	25
T-Grade 6	45	25	30

The results of the XRD analysis on the C-Grade samples are similar to that of the T-Grade material, with the majority of the 9phi minerals classed as albite (45-55%) and the rest consisting of augite (10-30%) and halloysite (25-30%) [Table 5.11].

Table 5.11 X-ray diffraction results from the C-Grade (9 phi fraction) samples

Sample	Albite (%)	Augite (%)	Halloysite Kaolinite group (%)
C-Grade 1	50	20	30
C-Grade 2	45	25	30
C-Grade 3	40	35	25
C-Grade 4	45	25	30
C-Grade 5	55	10	25
C-Grade 6	55	15	30

Material was collected from between the fractures of the G-Grade face. It was yellow in colour and appears to have a clay-like consistency with larger particles within it. It was moist, and found throughout the rock face. It was difficult to collect a large amount, sufficient for removing the 9 phi fraction by the settling method described in Appendix D. The sample was air dried and sieved over the 53 µm sieve. The sieved material was ground down to the 9 phi fraction and subjected to X-ray diffraction analysis. Although these results give an indication of what the in-filling material contains, it is not a true representation of the clay sized fraction, but rather one of the silt fraction. These results correspond with those tested at the 9 phi fraction; the same minerals were present, except there was no augite concentration as with the other samples (T, C and G – Grades), and the concentration of the halloysite was slightly higher (Table 5.12).

Table 5.12 XRD results from samples of in-filled material collected from the fractured G-Grade material (53 µm fraction ground down to 9phi)

Sample	Albite (%)	Halloysite Kaolinite Group (%)

In-filling 1	45	55
In-filling 2	50	50

Two samples of the Miners Rd quarry material were analysed using XRD. The dominant mineral making up half (50%) of the clay sized material is quartz, with albite and augite making up 25% and 15 % respectively (Table 5.13). There were two clays, halloysite and illite, found in the clay sized fraction, with a contribution of 5% each. Neither of these clays is expansive. Quartz is a commonly occurring mineral, and can be expected in sedimentary rocks.

Table 5.13 XRD results from the Miners Rd quarry (9phi fraction) samples

Sample	Albite (%)	Augite (%)	Quartz (%)	Halloysite kaolinite group (%)	Illite (%)
Miners Rd 1	25	15	50	5	5
Miners Rd 2	25	15	50	5	5

The additional material collected for the revised NZTA T20 method, in section 5.1, was analysed by XRD. The three pad samples all returned the same results with a high concentration of albite and some augite (Table 5.14). There were no clays present which raised a concern, and a second opinion was sought. Following in-depth discussion it was deemed that the method conducted in the XRD analysis was sufficient in determining the clay type and content. The lack of clay content in these samples was put down to sample preparation, and not the analysis from the technicians. It is important to ensure the correct preparation technicians are observed and that the clay minerals are able to orientate themselves for correct identification. If the method, detailed in Appendix K is followed then this will be achieved.

Table 5.14 XRD results for Pad A, B and C from PLQ tested on the 9phi fraction

Sample	Albite (%)	Augite (%)
Pad A	85	15
Pad B	85	15
Pad C	85	15

The 18 samples tested using XRD, (six from each grade of weathering) indicated similar compositions to each other. The most notable identification was the concentrations of halloysite (non-expansive clay) and montmorillonite (an expansive clay) in table 5.8. The montmorillonite was only found as a trace (less than 5%) in all of the G-Grade samples. This could indicate that the degree of weathering could be related to the degree of alteration and subsequent clay content, although no conclusive evidence of this was found when analysing the thin sections The T-Grade and C-Grade samples had similar concentrations of halloysite between 25-30% whereas the G-Grade samples only contained 10%. The identification of the halloysite clay minerals in all the samples coincides with the non-plastic PI results as halloysite is generally non-plastic.

The in-filling clay collected from the open fractures of the G-Grade face contained only halloysite. The in-filling clay material was not prepared in the same manner as the other samples and therefor the results cannot be used to draw any conclusions, other than to confirm the presence of Halloysite.

The control stone from Miners Rd Quarry had minerals present similar to that of the PLQ aggregate. This could not be clarified as no previous mineral analysis had been completed on the quarry source before. It is interesting to note the clay fractions are so similar. Quartz is within the Canterbury greywackes and has a high reflective peak which at times can mask other peaks making it difficult for the XRD software to identify the other minerals accurately.

The use of XRD is widely disputed within the industry and relies heavily on the experience of technician using the machinery and interpreting the results, the preparation of the sample and the capabilities of the equipment. The technicians at the University of Canterbury have years of experience behind them and work as a team to analyse each data set. Therefor a definite conclusion can be made that the clay content within the PLQ aggregate from these samples is Halloysite and not montmorillonite.

5.6.6 Scanning Electron Microscopy

Scanning electron microscopy (SEM) was conducted on rock fragments which were freshly broken under a press to reveal a surface not previously exposed to the elements. The samples were then dried and mounted onto a stub using araldite. It was important to obtain a sample that had two parallel and flat surfaces for imaging. The fragments were approximately 20 mm x 20 mm x 5 mm. The samples were then carbon-coated to provide a medium for the electrons to be transmitted. When fixing the sample onto the SEM mount table, the table was comprised of carbon to create a continuous medium from the stub over the sample and back onto the stub again; this improves image quality.

Three samples were prepared for testing and analysed over two sessions. The C-Grade and G-Grade samples were prepared from a press crushed rock, to expose a fresh surface that was collected before crushing. The weathered sample was prepared from a G-Grade rock also collected before crushing, but was selected to include a surface that had been exposed to the elements. The images were taken in both secondary electron imagery (SEI) and back scatter electron (BSE) modes. A detailed explanation of SEI and BSE can be found in Appendix D. Nomenclature identifies the sample first, followed by the position or image number to differentiate between the locations on the sample; a full catalogue of the SEM imagery can be found in the Appendix N.

The weathered sample (W-01) image was taken in BSE mode; the bright white areas in Figure 5.20 indicate atomically heavy minerals, whereas the darker colours indicate areas with atomically light chemistry. The crystal boundaries are weakest, indicated by fracturing around crystals. Fracturing can be caused by stress when lithifying, or stresses induced over time; they can also be introduced by blasting, crushing and drying of the rock. Some of these fractures are in-filled; this is notable where a differing brightness is visible between two crystal boundaries. The uneven pitted-like texture shows areas of dissolution. Bright white-spotted minerals are formed from either a constructive or destructive process; the mineral has either dissolved out of a solution or has precipitated there from another source.

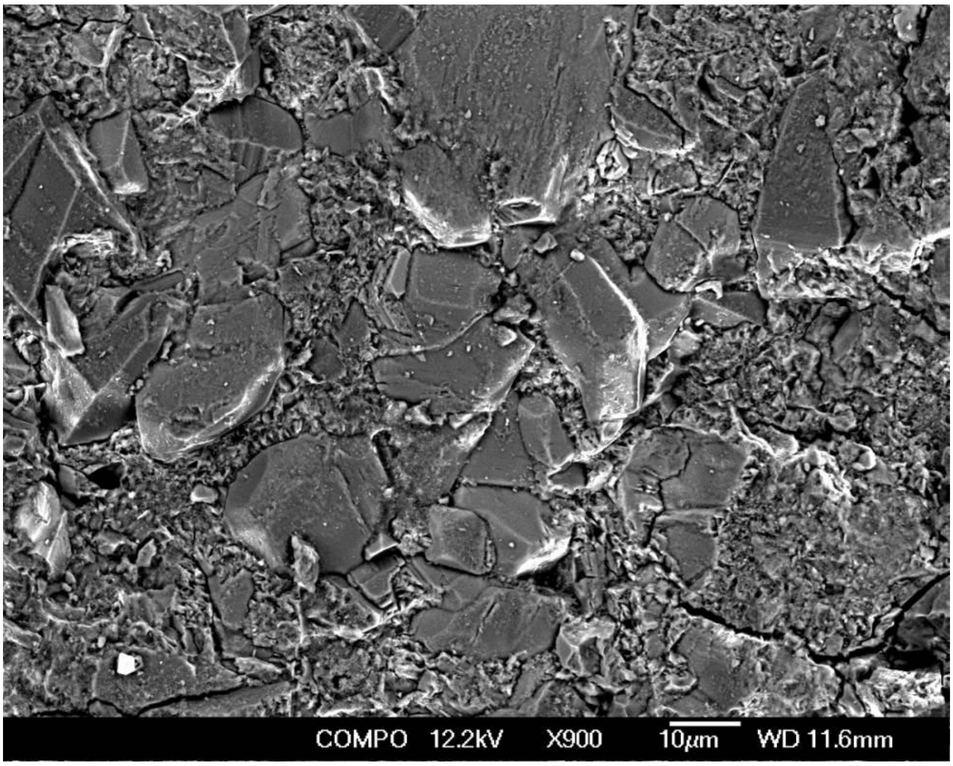

Figure 5.20 Image of sample W-01 under a scanning electron microscope in back scatter electron mode

The image of sample W-02 (Figure 5.21) was taken in BSE mode. Smooth uniform looking minerals with distinct edges have not undergone dissolution or corrosion. Fracturing, due to stresses in the field, is evident around the crystal boundaries. The matrix made up of smaller mineral is less stable and has undergone corrosion; this uneven pit-like texture was evident through-out this sample. The "piano-like" structures are the result of dissolution, where the least stable areas of the mineral have dissolved out leaving behind the more stable structures. These have formed along the lamination as two terrace like structures are remaining. The lamination is found along the same surface as the piano-key structure.

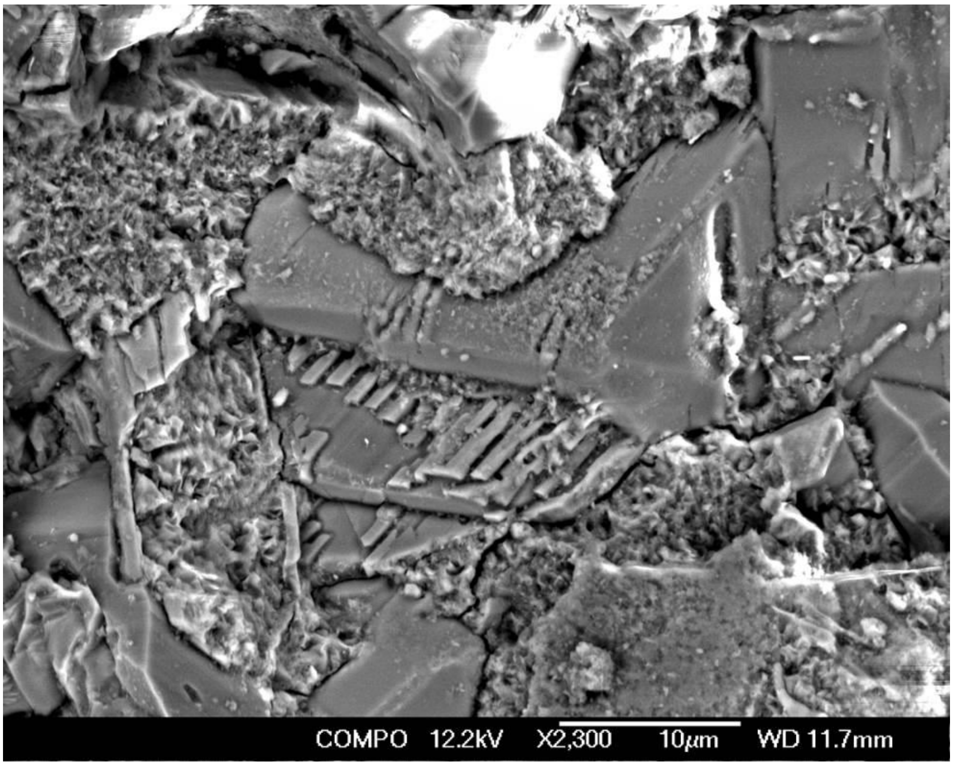

Figure 5.21 Image of sample W-02 under a scanning electron microscope in back scatter electron mode

The right side of the image of sample C-08 (Figure 5.22) shows evidence of dissolution along a lamination plane; this is evident by the non-dissolved planar crystal structure of the same orientation and shape directly behind it. This shows that the dissolution is preferred along this lamination. The centre of the image shows a more atomically heavy mineral, likely to include iron. This fabric holds no shape or form of the previous mineral due to the dissolution process. There are fibrous like forms on the edges of the structure which show degradation on the inside of the mineral. There are also possible fractures between what could have been mineral grains.

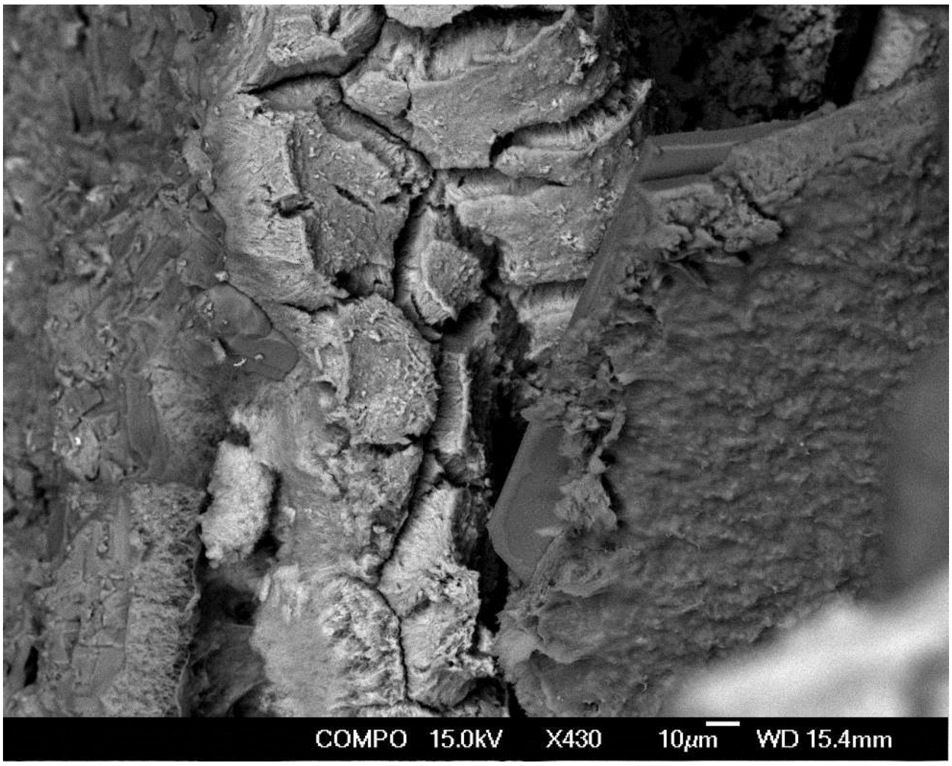

Figure 5.22 Image of sample C-08 under a scanning electron microscope in back scatter electron mode

Sample C-13 (Figure 5.23) shows an obvious lineation (left bottom corner to top right corner). The image in Figure 46 shows the difference between SEI and BSE modes. Identify the difference between the two imagery grey scale differentiating between chemistry is more evident in the BSE. The dissolution fabric (dotted, dust appearance) is more visible in the SEI image and the fabric is more prominent. The BSE image is an enhanced image showing the dissolution textures more clearly (bottom right hand corner of BSE image), but does not show the speckled dusty look as evident in the SEI image. The area has fracturing around the minerals, but this not as distinct as that shown in the other figures. The mineral in the middle of the image has cool cracks indicated by lines on the smooth surface which run almost parallel to one other; they are not open cracks or fractures.

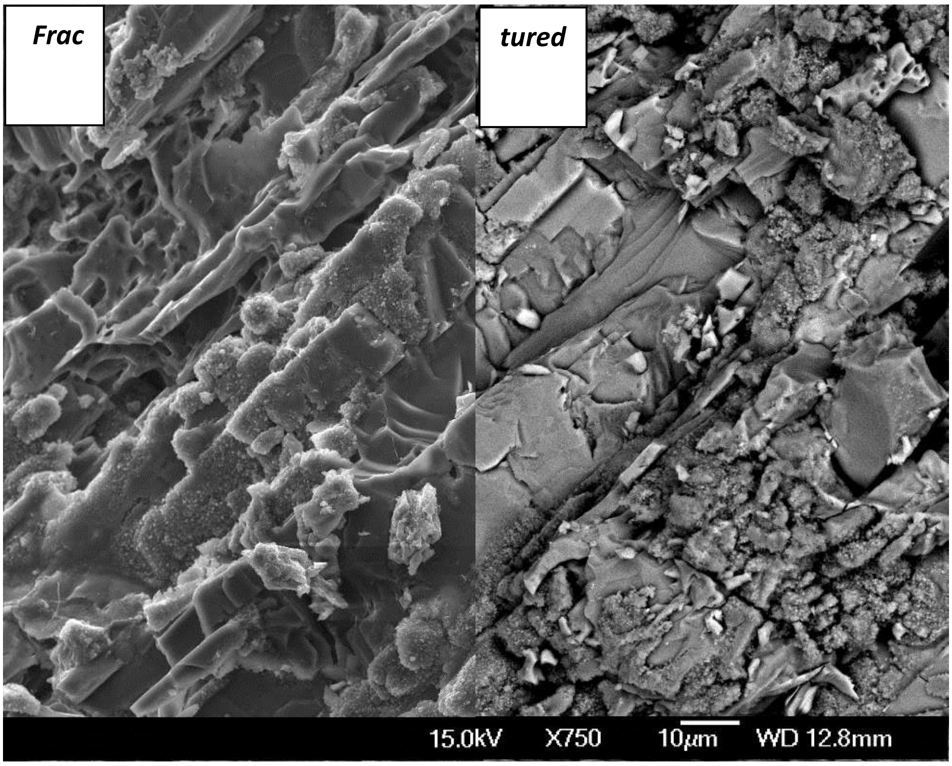

Figure 5.23 Images of sample C-13 under a scanning electron microscope in back scatter electron (BSE) and secondary electron imagery mode (SEI). Identify the difference between the two imagery grey scale differentiating between chemistry is more evident in the BSE. Different dissolution textures are visible in the two images.

The images of sample G-13 shows areas of extensive dissolution and areas where parts of a mineral are unaltered. These textures are likely to have occurred in the field after mineralisation but before the blasting process of quarrying. The bright mineral in the top left is likely to be hematite or magnetite (Figure 5.24). These minerals are iron rich and show up as opaques in thin section, and were identified. Fracturing is evident around minerals and continues to extend through some minerals. The highly altered areas are likely to be microlite and minerals, which are less stable and therefore alter first. The rectangular mineral in the centre of the image is being altered from the inside out. This is similar with some of the plagioclase in thin section, with the less stable centre probably being sodic-rich with a more calci-rich rim. There is no uniformity within this image, and it appears that there are multiple areas of dissolution. The lighter areas on the edges of the minerals show areas of differing chemistry, and highlights the areas that are in the early stages of alteration. This is also supported by the observation that areas that have already undergone alteration and show dissolution textures are generally brighter than those that have not; this is particularly notable in the top centre of the image.

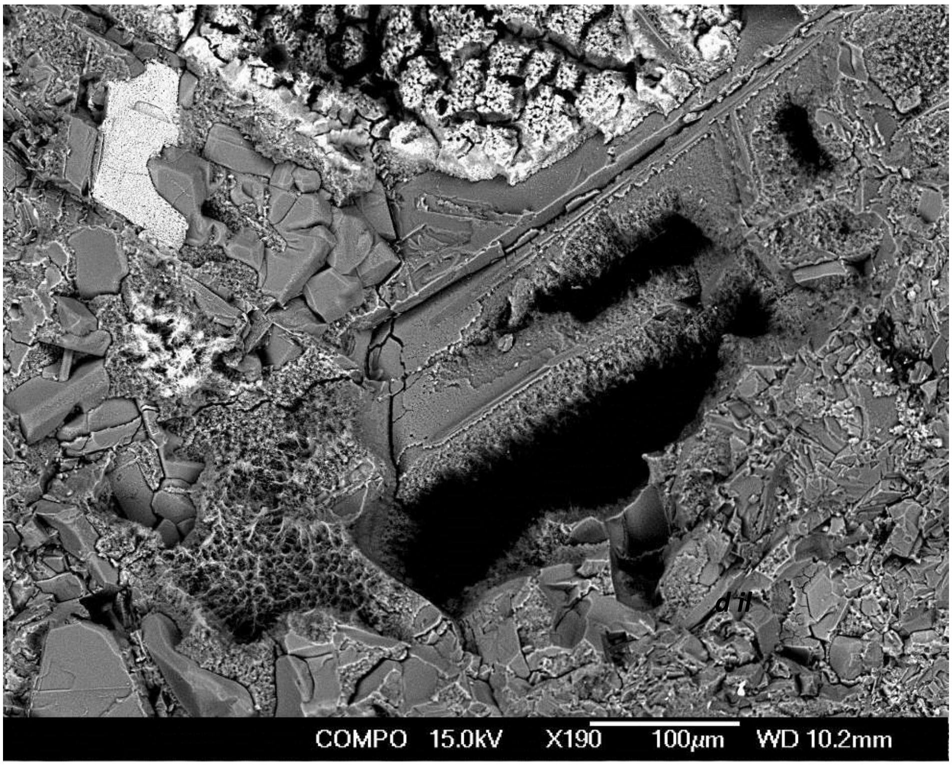

Figure 5.24 Image of sample G-13 under a scanning electron microscope in back scatter electron mode. The iron rich minerals show as bright white. There is extensive alteration throughout the image. The lighter edges of the mineral indicate the beginning stages of alteration

The SEM analysis identified extensive mineral alteration throughout the weathering grades. Most sites analysed were areas previously selected due to some optical identification (colour changes and staining), and therefore are biased toward the possibly the worst areas, in saying that the extent of alteration cannot be ignored. It is likely that this alteration continues throughout the rock mass as thin section analysis indicates that alterations aren't concentrated in specific areas or to specific minerals but is evident over a vast majority of the rock specimen.

The SEM does show that the ground mass or matrix is susceptible to alteration as the particles are smaller and possibly less stable. The larger Plagioclase minerals are also more susceptible to dissolution particularly from the inside out suggesting that the chemistry of the mineral changes, possibly more sodium rich on the inside which is less stable and calcium rich on the outside which is more stable and therefore less susceptible to alteration.

5.7 Fracture Analysis

The term fracture analysis was used in the paper to describe all failure planes within the rock. These failure planes were either formed after placement and cooling of the lava due to stresses in the field, or due to blasting and processing. This included all analysis from macro to micro scale; quarry face mapping, hand sample analysis, optical microscopy and scanning electron microscopy. The failure plane analysis was initially intended to determine if the crushing process imposed further detrimental stress on the rock, but it was determined that the method would be insufficient in accurately identifying the change in fractures from a hand scale size to then supply it to a large scale volume of product. From there it was decided that the fracture analysis would be conducted on three varying scales to identify if any trends existed from large scale (macro) to micro scale. The macro scale was investigated by the mapping procedure that identified joint sets, faults and other discontinuities (Chapter 3.4). Hand samples collected at the face were analysed and prepared into thin sections (Chapter 4.6.2) and then scanning electron microscopy (Chapter 4.6.6) was conducted to investigate the nature of the fracturing on a micro scale.

The mapping conducted at the face of each weathering grade highlighted the large scale nature of the rock type. The G-Grade material was predominantly more weathered with many more faults and joints in some cases it resembled a rubbly material with not much structural integrity. The weathering profile decreased through the other rock faces, from the T-Grade material (moderately to well weathered) to the C-Grade face which was the least weathered.

Hand section analysis showed that the G-Grade sample had 20-30% more open veins within its fabric and more closely spaced than the other grades. Tis coincided with the mapping as both indicated increased weathering. The number of veins, spacing and aperture decreased as the weathering decreased. The lineation of the veins was consistently present through all three grades.

The thin sections continued to display this trend of increased weathering displayed more defects, larger and wider micro-veins and elongated vesicles. Micro veins were open (up to 5mm) in the more weathered G-Grade material and as the pinched and swelled, the micro-veins were filled with microlites and often showed evidence of iron staining and iron oxides.

The SEM analysis indicates that fracturing is extensive in some areas of the samples, but then not evident in others. The nature of the fracturing is such that its preferred orientation is around mineral grains, and in some cases through minerals. This decreases the strength of the rock as the mineral grains generally interlock which gives it its strength but this is compromised with fracturing between the grains. Some fracturing can be identified as historic as other minerals have overgrown the crack or in-filled the spaces, but for the majority of the fracturing it is difficult to pinpoint a cause or time scale. These may be pre-existing or could have been introduced from blasting, crushing or when drying the sample to analyse.

In conclusion the failure planes of the aggregate is an important factor to consider when analysing the durability of the rock. There are areas in the quarry which is more weathered than others as seen with the face mapping of the grades. It was found that the more weathered the rock is the more the micro-veins become open fractures up to 5mm wide. This was confirmed with the thin section analysis which also identified the iron staining of the micro-veins as well as in-filling of iron oxides and other minerals (similar to those in the matrix). Fracturing was also noted through minerals and often followed the path around minerals grains. These were more likely to be historic fracturing and not introduced by processing due to the staining often associated with them. The SEM analysis looking at a micro scale found fracturing around the grains of minerals and some through minerals. These failure planes may be a detrimental failure mechanism that might have been over looked in the past. When stress conditions changes such as increased poor pressures, loading or environment changes this could cause pavement failures and ultimately aggregate breakdown.

5.8 Summary of Evaluating Additional Material Tests

Following the analysis of historic data and the analysis of the material to the M/4 specifications it was identified that the quality of fines need further investigation. A number of additional tests, including the Accelerated Weathering test and ITS test, smectite identification test, mineralogy analysis and fracture analysis.

The accelerated weathering test was amended a number of times and there were some inconsistences and discrepancies found within the data. None of the samples met the proposed 30% limit in the final when following the final iteration of the method. It is important to conduct more testing on a wider range of samples to include and investigate the performance of many different aggregates from around the country to ensure that good quality aggregate isn't being excluded from uses. It is also important to understand the effect of pore water pressure when testing at a surface saturated dry condition.

It was determined that by using 1% of cement within the mix the PLQ aggregate will meet a strength of 400 kPa. This is a target strength for the industry that will allow some flexibility in the pavement without compromising on strength. When conducting an ITS test on an ethylene glycol soaked sample the change in results were similar to that of the PLQ aggregate and the control stone, 68% and 60% respectively. It can be determined that if in fact the accelerated weathering test does indicate the durability of aggregate over time when exposed to water, then stabilising the material will not be affective if the aggregate has been subjected to moisture damage (clay expansive and subsequent aggregate break down).

The smectite identification test was deemed unnecessary to perform as it was developed for infield testing and generating quick results. It follows a very similar method to that of the CI test, and the results were very similar.

The mineralogical analysis confirmed the mineralogy of the PLQ aggregate. The dominant minerals are from the feldspar groups (K-spar and plagioclase) as well as from the pyroxene group (orthopyroxene and clinopyroxene); these two mineral groups make up both the porphyritic nature of the rock, as well as a large proportion of the matrix as well. Opaque mineral ranges from microlite size in the matrix to minerals up to 1mm. Alteration textures were dominant in the feldspars and fracture in the pyroxene minerals. The XRD result revealed that there is only a trace of montmorillonite in the G-Grade samples, and the dominant clay is halloysite, which is non-expansive. Halloysite is generally a non-plastic clay and coincides with the non-plastic results returned from the PI tests (Chapter 4.5.3). The SEM analysis could not determine the abundance of any particular clay but evidence of large alteration was seen in all the samples.

None of the three methods were used as conclusive evidence for determining clay minerals, but in conjunction with one another and as well as having the expertise of experienced technicians, it can be concluded that only a trace of deleterious minerals (i.e. montmorillonite) were found within the PLQ aggregate. This is not to say that there are no smectites within the aggregate source but that/ variability within the quarry is extensive and provisions need to be made to allow for the detection of swelling clays as the CI test is insufficient. A course of action should be developed if the durability is compromised by the presence of these clays.

The thin section analysis and the SEM confirmed that large scale alteration is notable throughout the samples with little variation between the three weathering grades. This indicates that the minerals are susceptible to alteration and breakdown which will compromise the strength of the rock.

5.9 Synthesis

The objective of the research was to understand and demonstrate the effect of aggregate properties on a pavements performance. This section summarises how the test results from Chapters 4 and 5 contribute and effect each of the following; basecourse failure mechanisms, basecourse degradation, and clays in aggregates that were introduced in the literature review (Chapter 2.4 -2.5). It is not only important to understand the test results but also understand how they can be interpreted to determine pavement performance.

5.9.1 Basecourse Failure Mechanisms

Basecourse failure mechanisms covered in the literature review included; permanent and resilient deformation, moisture content, fines content and gradings and number of load applications.

5.9.2 Factors Effecting Permanent and Resilient Deformation

A number of factors affect the resilient modulus, and permanent deformation. These include; stress, density, moisture content, fines content, grading, aggregate type, number of load applications, load duration, frequency and load sequence (Uthus 2007 and Lekarp 1999). It is important to test for these mechanisms to help identify if either one or couple together they are a major contributing factor to basecourse degradation.

Although the roads in New Zealand are based on empirical design the majority of testing is conducted mechanically, but most of the factors listed by Utus (2007) and Lekarp (1999) have been tested for in this research.

Stress was not tested for in this research as equipment was not available but can be calculated when samples undergo a Repeat Load Triaxial test (RLT). In 2006 a report by the University of Canterbury was released, issuing the results of Repeat Load Tri-axial test conducted on PLQ basecourse on natural specimens and specimens with differing percentages of lime, cement and foamed bitumen. The material was sampled from a stockpile at PLQ as well as including material from Route K. Twenty seven (27) tests in total were performed (University of Canterbury, 2003). It was concluded that cement will improve the plastic deformation resistance, and both the lime and foamed bitumen were unsuitable as an additive for plastic deformation resistance improvements. This was an important factor when considering a course of action for this research. From this it was deemed necessary to investigate the use of cement as a stabiliser. Testing was conduct using the ITS method which indicates a strength in measured kilo-Pascal's (kPa). This may not directly measure the stress threshold but does give an indication of what the strength of the material is after stabilising when but under load.

The CBR result is an indirect measure of an aggregate's strength, even though it cannot be used directly in pavement design it can be correlated to the resilient modulus. All the CBR results were from samples tested in the lab and show that the aggregate consistently performs well even when other characteristics for the aggregate are quite variable.

Moisture Content

It is well documented that excess moisture within a pavement can lead to premature failures (Koroma 2011, Saarenketo, et al. 2001 and Stevens & Salt 2011) This not only related to the moisture of the aggregate when being laid but also the effectiveness of the drainage within the pavement. Although the drainage of pavements in the BOP was not analysed, the moisture of samples was controlled for testing purposes.

The moisture content is not required to be recorded in the M/4 specification but was done so to provide more information. It was deemed that the samples would be corrected to an optimum moisture content (OMC) of 6.5% which was not always suitable, it was found that this was too high and later scaled back to 6%. This number was chosen as the Compaction curves indicated a OMC of 7.5% and 8.5% for material sampled in 2015, this was notably too high and therefore a lower value was chosen.

When compaction was required such as CBR and ITS it was necessary to obtain optimum moisture content otherwise the sample would not compact effectively or the increased water content would provide a medium for the fines to move out of the system. It was important to obtain a standard within the testing to ensure results were comparable. The soaked ITS blocks showed signs of over saturation likely due to the EG infiltrating the rock and not evaporating when drying in the oven (mass reading did not differ by 0.1%)

Fines Content and Grading

The grading of an aggregate is typically governed by the PSD which provides an envelope by which the material must comply. Talbot's grading curve is used to define coarse and fine aggregates and has been introduced into the new draft specification with the SGE and the grading control factor. New Basecourse is typically graded between 0.3 and 0.6 but then new grading control allows from 0.3-1.0 for each sieve size range. This control allows for the accurate assumption of how the Basecourse will interlock ensuring that there are enough fines to fill the spaces created when the larger stone interlocks.

The fines content is measured using the Sand Equivalent and then the nature of the fines are tested using the CI and PI. The PI, which gives an indication of how plastic the fines in an aggregate mix are, showed that there is variability within the quarry. This may genuinely be the case with fines content changing in composition and nature around the quarry or the testing may be compromised by inexperienced technicians. There was no correlation with the CI and PI. The clays identified are Halloysite which is non-expansive clay and may correlate to the PI which was non-plastic for all samples.

The PLQ doesn't follow the expected trend and the higher the SE ratio the higher the CI value, which means that when the fines concentration was low the CI was higher. This highlights how the test may need amendments, where the settling time may need to be adjusted for each aggregate source (Lowe, Wilson, & Black, 2010).

The broken faces test is conducted to ensure the friction between particles is sufficient enough to provide an efficiently interlocking matrix. Although this doesn't change the grading as such it does provide the necessary framework for a structurally sound pavement.

Number of Load Applications

The following tests indicate the response of the material to load applications, Crushing Resistance, CBR and ITS (RLT can also be used but will not be focused on in this project). The Crushing Resistance consistently meets the standard often exceeding it by a large margin. This demonstrates the resilience and durability of the aggregate under controlled conditions. The expected durability of the aggregate over time and the degradation caused by cyclic loading is not a result of this test. The CBR results also shows that the material preforms well under theses loaded conditions but as with the Crushing Resistance test is in a controlled, confined condition. The ITS results indicated that by stabilising the basecourse with only 1% of cement the aggregate will perform well under stress and loading.

The load under which the pavement will be subject too is governed by a number of factors such as the location, traffic conditions, road type. This will all be pre-determined in the design before the construction can begin, but these test result are beneficial in providing inputs and giving an indication as to how the aggregate is expected to perform.

Basecourse Degradation

Basecourse degradation takes into account all the failure mechanisms discussed but also includes factors which cannot be tested for in a laboratory. Climate, traffic conditions, design drainage and material source all influence the degradation of the road, these influences will need to be taken into account for any pavement design but were not part of the scope of this research.

The Weathering Quality Index is a good measure of how the aggregate will withstand a number of extreme environmental changes which include the alternating periods of soaking and drying (at high temperatures) as well as repeated rolling under load. An indicative measure can be drawn as to how well the material will endure these different conditions combined.

Crushing Aggregates

The PLQ aggregate is initially categorised by the mapping profiles and then further classified by the material which surrounding the blast site and also the condition of the material after its blasting release.

The crushing plant requires all aggregate irrespective of the final product to be passed through the Primary plant. For the TNZ AP40 the aggregate is then passed through the Transit plant and processed accordingly. It was initially thought that a hand sample of aggregate taken from the stockpile before crushing and one hand sample taken from the stockpile after crushing would give an indication as to what stress the crushing plant put on the aggregate and if it was causing any further breakdown. From analysis of the rock taken before crushing and after crushing no conclusion could be drawn. This was due to the fracturing nature of the rock and the alteration being so advanced that it would be difficult to identify new fractures that had been introduced due to processing and that the hand sample would not effectively represent the aggregate. The same hand sample (a single piece of rock) would need to be analysed before and after crushing and it would prove difficult to track it through processing plants.

The fracture mapping indicates that the more weathered material has a higher frequency of fracturing and joint going from a large scale (face of the quarry) down to micro scale, where open fractures where notable in hand sections and when conducting microscopy. The finite scale indicates some fracturing with crystal overgrowth implying the fracture was not introduced by processing. Other fractures are difficult to classify and historic or introduced from blasting and crushing.

Clays in Aggregates

The CI test indicates clays are present which is accurate but doesn't give an indication of concentration or types of clay. Previous studies identified smectites in abundance within the PLQ aggregate; this may be the case and explains the variable historic PI results. An additional method was introduced to determine the concentration of clays but proved to be unnecessary as the results and method were very similar to the CI values.

The data indicates that although this measure is important to use for indication of clay content it does not provide the beneficial information on what clays are in the system and how they may behave when exposed to moisture. The durability of the aggregate is larger influenced by the nature of the clays and the concentrations throughout the rock. This has been expressed as a concern within the industry and therefore the Accelerated Weathering test was developed. The data shows that no conclusive results for determining the durability of a rock can be deduced. The method needs to be revised and an inventory back by substantial research needs to be conducted before being published.

A more effective way of determining the clay composition should be developed. XRD analysis is useful but relies heavily on the technician and the accuracy of the equipment. This coupled with mineral analysis where optical microscopy or SEM may give a better indication of the clay content. This equipment and testing would need to be outsourced, but results could be obtained within a few days if sent off for testing.

6. Chapter Six Summary and Conclusion

6.1 Thesis Scope & Methodology

Poplar Lane Quarry (PLQ) is owned by Fulton Hogan and is located in the Bay of Plenty, New Zealand Geolgoy. The quarry is situated in the Otawa Formation, which is comprised of dark grey, fine- to medium-grained porphyritic andesite lavas containing phenocrysts of plagioclase, hypersthene, hornblende, augite and minor quartz. The purpose of this research was to assess the utilisation of Poplar Lane Quarry (PLQ) basecourse aggregate as a suitable source for roading material. Poplar Lane Quarry (PLQ) basecourse aggregate generally, but not consistently, meets the current M/4 specifications, and the effect of proposed revisions to M/4 on consistently satisfying required properties of M/4 is unknown.

This was conducted by reviewing historical M/4 test reports and comparing them to the M/4 specification. Material was collected from Poplar Lane Quarry to conduct M/4 testing to obtain a full range of material properties, as well as additional analysis methods. This included investigate the geology of PLQ and determine and confirm its mineralogy and any susceptibility to alteration, including formation of deleterious minerals in certain layers. The mineral analysis was conducted using optical microscopy, x-ray diffraction and a scanning electron microscope, this included the identification of clay minerals with a particular focus on smectite clays. Lastly the fracturing characteristics of the rock was investigated to determine its effect on the aggregate. A Canterbury alluvial greywacke was used as a control stone as it is known to be a high performing aggregate.

6.2 Principal Results

Three differing weathering grades were identified within the quarry (G-Grade, T-Grade and C-Grade) and these were processed to manufacture TNZ M/4 product. The G-Grade material was the most weather ranging from highly to completely weathered, T-Grade ranged from moderately to highly weathered and C-Grade was the least weathered ranging from slightly to moderately weathered. These three grades were chosen to establish the range of material properties and its effect on the M/4 product. These three grades were subsequently sampled and tested according to the TNZ M/4 specification and additional test. All historic M/4 test reports were collated and correlated. The results from both the historic data and current data indicate the PLQ AP40 meets the standard set out in the TNZ M/4 specification. There were two tests which highlighted potential issues and caused for further investigation. They include the Plasticity Index and Clay Index results. The Plasticity Index showed variable results with only 51% of results meeting the specification and 37% of all the results were non-plastic, although some results were as high as 17. It was highlighted that the variability can a result of two factors, one being the variability of clays within the quarry as clay type and content affect the plasticity. Two, it can be contributed to by the competence of the laboratory technicians. The Clay Index consistently does not meet the specification, but the understanding of how the test works is imperative in understanding the result. The Clay Index values ranges from 3.1 to 10.8 with the specification stipulating the results must be below 3 to pass. Some people in the industry assume the test is an indication of smectite (or swelling clays) and the higher the Clay Index value the high the clay content. This is not always correct as the methylene blue used as an indicator in the test will react with most clays and could react with any particle that have a surface charge. As the test is conducted on a silt fraction, it may indicate the presence of non-clay particles, thereby increasing the CI value if those particles react with the methylene blue.

6.3 Mineralogy Results

The mineralogy analysis indicated a relatively homogenous composition between all three weathering grades, but some minerals exhibited a large variation in mineral size, shape and textural composition. The main minerals present were plagioclase feldspar, potassium feldspar (k-spar), orthopyroxene, clinopyroxene, opaques, glass and iron oxides. Plagioclase dominated the mineral assemblage and was commonly the largest phenocrysts up to 5mm. Glomeroporphyritic texture was found in all samples and was often confused as a single crystal before examination by microscope. The matrix was predominantly made up of all the minerals present and displayed aphanitic texture. Alteration was evident in all samples, with the majority of the plagioclase minerals having undergone dissolution, generally in the middle with the rim remaining intact. This was possibly due to a chemistry change, and therefore a stability variance between the rim (Calcium rich) and centre (Sodium rich).

Mineral alteration was not variable between the three weathering grades. Although the sampling sites were positioned in different areas they were relatively close when scaling against the whole quarry. This made it difficult to determine any lateral or vertical variability, but it can be concluded that in the South East of the quarry there was very little variability. The thin section analysis identified mineral alteration throughout all three samples and this was confirmed with the SEM analysis. The Scanning Electron Microscope analysis indicated extensive alteration in most minerals with the matrix of the rock altering first. This may be a contributing factor to aggregate breakdown as the mineral strength is decreased when alteration has occurred.

The XRD analysis identified that the most abundant clay mineral was halloysite (25-30%), which is non-expansive. This was not expected as previous research identified smectite clays which are expansive. There was virtually no evidence of smectite clays, only a trace (<1%) of montmorillonite found in the G-Grade samples. Montmorillonite is part of the smectite group, but was not flagged as a concern because the concentrations were so low. It was determined that the degree of weathering was not related to the degree of alteration because the concentration of clay minerals was least in the G-Grade material which was the most weathered.

6.4 Fracture analysis

The fracture analysis was termed to encompass analysis of failure planes within the aggregate. These failure planes were pre-existing before blasting and formed after placement and cooling of the lava due to stresses in the field. This included all analysis from macro to micro scale; quarry face mapping, hand sample analysis, optical microscopy and scanning electron microscopy. The initial fracturing analysis method to be used was discarded due to the possibility of bias and therefore it was difficult to determine the effect the processing and production had on the aggregate. From the fracturing analysis that was conducted it could be determined that there are areas in the quarry with a higher degree of weathering and would probably produce less quality aggregate. The quarry face mapping identified the joint set data, faults and other discontinues. The G-Grade material which was the most weathered showed evidence of open fracturing which could be attributed to elongated vesicles (up to 3mm) wide in the hand sample and was reconfirmed when investigating the thin sections. These pinched and swelled, Fracturing was identified in the thin sections, at times these fractures pinched and swelled to form the open fractures. The micro-vein would also eventually break apart to form an opening, at their finest they resembles hair line fracture through the rock. The majority where in-filled and had iron staining. The SEM analysis identified fracturing in and around minerals particularly notable in areas of higher alteration. The fracturing followed a preferred path around and between mineral grains which affects the strength of the rock as the minerals are no longer interlocking. At times the fracturing dissected minerals and this was seen in thin section too. It was difficult to determine when and why the fracturing took place. There was evidence of mineral overgrowth and in-filling which identified historic fracturing, but other fractures could have been introduced from a number of processes.

Two significant additional tests were performed on the PLQ aggregate. The first test, Accelerated Weathering test, was intended to determine the durability of the aggregate. The results showed that the PLQ aggregate has a large variability, and results may not give a definite indication of the durability as the control stone produced variable results. The control stone is known to be a durable well performing aggregate. After talking to the author of the Accelerated Weathering test it was found that the test had been revised after the testing regime for this research was completed. When following the newly suggested method (percentage difference) it proved unreliable as one of the control stone samples failed where the other passed. The control stone is known to be a good quality aggregate and not have any durability issues. The method was revised and further testing was done on additional material that was brought in. This again indicated a poor durable product for both eh Polar Lane Quarry material and the Canterbury greywacke, with all samples having a percentage change over 30%. This is of most concern as it would be unrealistic to exclude such a well performing product based on this test and therefore further investigation needs to be conducted by the test method authors. It is important to note that the highest quality ethylene glycol should be used for testing (99% and above). Availability issue may arise if the test is implemented. Recycling or disposal processes will need to be addressed.

The Indirect Tensile Strength test was the second significant test conducted on the aggregate. It was deemed necessary to stabilise the material to improve its durability. After the clay analysis determined a non-expansive clay present in the rock it was decided that the fracturing may be the major contributing factor to the breakdown of the aggregate. The aggregate was stabilised to determine if it could improve the durability of the aggregate and lessen the implication of the fractures. It was found that stabilising with 1% cement will achieve an Indirect Tensile Strength of 392 kPa which is very close to the desired upper limit of 400 kPa.

In conclusion, the Accelerated Weathering test needs some improvement and research before being published and brought into routine production testing. The Indirect Tensile Strength tests indicate that if the aggregate is compromised by either fracturing or clays it can be strengthened by the use of a cement stabiliser.

6.5 Conclusions

It can be concluded that the PLQ AP40 basecourse met the TNX M/4 specification majority of the time. The results of the PI and CI test did not always meet the specification and can be put down to variability in the quarry rock and the appropriateness of the test method

The main conclusions that can be drawn for this research are detailed below.

1. The PLQ TNZ AP40 continues to meet the requirements of the current and draft specifications when using the samples collected from the three grades of weathering. The additions to the draft specification are still met by PLQ but may need to be monitored to ensure changes in requirements are still being met. Exact locations of material extraction need to be recorded to identify trends or areas where the test results change.

2. The Clay index test was the only test which consistently did not meet the M/4 specification. On further investigation it was found that the test my not be fit for purpose. The methylene blue used in the clay index test can react with other particles and give a false indication of deleterious clays. It also does not give an accurate indication of content or clay type.

3. The Plasticity Index, although in the past did not always meet the speciation did so in the three weathering grades of this research. The results were all non-plastic. This change from the historical results can be attributed to the variability within the quarry as with the clay types or it could also be attributed to the competency of the technician. A method for changing or decreasing the PI value could not be conducted because all of the samples were non-plastic.

4. Halloysite was found as the clay type within the aggregate; this is a non-expansive clay and will not react with moisture. There were some traces of Montmorillonite found in the more weathered samples but this was less than 5% of the clay particle sized sample and thought to be insufficient in the durability of the aggregate. This highlights the variability of clay type and content within the quarry. It is likely that research done in the past by Bartley et al. (2007) was correct in stating that smectites were present but they may not be found in all of the quarry rock. **Note** the correct procedure for XRD analysis is essential for the

identification of clay minerals. It is important the technician conducting the test allows for the orientation of clay minerals for accurate results.

5. The proposed Accelerated Weathering test is designed to give a greater indication of durability based on different clay types and their concentrations but the test method needs finalisation. Additional testing on a larger population of aggregate sources in New Zealand proposed. The intention being to obtain a greater understanding of the test and fully understand its contribution to the wider aggregate industry. The overall objective of this improvement is to ensure that good quality aggregate is not ruled out as an aggregate source.

6. After the fracturing investigation and determining the clay as non-expansive it was deemed suitable to improve durability by creating cementation of the basecourse. Stabilising the aggregate with 1% cement would help in achieving good durability. This was decided on after ITS testing revealed that 1% was the most effective and economical approach to increasing the durability of the aggregate.

6.6 Recommendations

- Investigate a suitable and economical method in determining the clay type and content. This will provide further information on the clay content and therefore not fully rely of the CI test as it could be misleading. This can be conducted using XRD analysis. Research into an industry recognised rapid test should explored.

- Determine the variability of clay content through the quarry by sampling different (inducing lateral and vertical variation) areas extracted for production. Where possible analyses using XRD and thin section microscopy should be conducted to gain further understanding of the mineral assemblage, clay content and variability throughout the quarry.
- Record exact areas of extraction and correlate to test reports, this will provide a more comprehensive guide as to where changes or trends occur. This will allow for a better interpretation of the quarry and aggregate. This, coupled with the knowledge and skillsets already established, will aid in the selection of good quality aggregate.
- Conduct interlabs to ensure that laboratory technicians are properly trained in PI test method. This will indicate if the competency of the technicians conducting the PI tests are causing inaccurate results or if the PI is variable because of the clay type varaibility. Provide equipment and training to Bay of Plenty laboratory and staff so that they have a greater understanding of the test method and how to identify changes within the aggregate.
- Conduct further analysis following the methodology in this research on other areas of the quarry identified as rich aggregate seams to ensure their M/4 compliance before introducing them to market.
- Where durability is compromised the basecourse can be stabilised with 1% cement which will achieve a strength reading of 400 kPa. If smectite clays are found in the future these can be controlled by the addition of cement or lime. The use of a cement treated basecourse (CTB) plant is recommended to achieve even distribution of the cement throughout the basecourse aggregate.
- Repeat the Accelerated Weathering test using the draft version (2016) and collate data to establish a better understanding of how the PLQ aggregate responds to the test. Correlate this data with other quarries to determine a consistent industry understanding of the test method and its relevance.

- Conduct field performance testing by analysis data from the in-field performance to identify any trends. Conduct property testing to further determine any changes in characteristics of the aggregate over time.

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A. Appendix A: Geology of the Tauranga Region

The PLQ quarry is found in the Papamoa range and comprises of late Pliocene Otawa volcanics. The Tauranga area formations range from the Late Pilocene volcanics to Pleistocene volcanics, with the later sequences being mostly rhyolite and dacitic (Briggs, et al. 1996). The Matua Subgroup of terrestrial and submarine deposits interlayers these volcanics.

The main physiographic units which make up the Tauranga basin Include; Kaimai Range, Whakamarama Plateau, Tauranga Basin, Marnaku Plateau, Papamoa Range and a group of volcanic domes (Figure 1).

The Tauranga region is bounded by the Kaimai ranges to the N and NW. Movement on the Hauraki fault, which bounds the range on the West, caused the uplift of the Kaimai range. It comprises of Miocene- Pliocene basaltic to rhyolitic volcanic rocks (Briggs, et al .1996).

The Whakamarma Plateau forms the base of the western portion, stretching from the Kaimai ranges to the Tauranga Basin. It dips in a north easterly direction at 3-5°. The plateau forms the basement below the Tauranga basin at depths between 50-150m (Briggs, et al., 1996).

The Tauranga Basin (570 km^2) is a Pleistocene, fluvial/estuarine basin. During a period of rapid subsidence the basin was partially infilled and comprises volcaniclastic terrestrial and estuarine sediments as well as welded and non-welded ignimbrites (Briggs, et al., 1996). The Tauranga harbour, a mesitidal estuarine lagoon, (200 km^2) occupies most of the basin. The main river into the basin is the Wairoa River which flows between the Whakamarama Plateau and Mamaku Plateau (Briggs, et al., 1996).

The Mamakau Plateau located to the south of the basin slopes at an angle of 1-2°. The plateau is a depositional feature comprising of pyroclastic flows formed in thick fans and lobes, this is underlain by the Mamakau ignimbrites and thins out toward the Tauranga Basin (Briggs, et al., 1996).

The Papamoa range is bounded to the south by the Mamaku Plateau an falls between the Tauranga and Maketu basins. It comprises of Pliocene andesitic volcanics, a series of Pleistocene dacitie and rhyolitic domes and dacitic ignimbrites. The alignment of the volcanic domes is thought, by Briggs et al. (1996) to be controlled by two NNE striking faults that border the range on either side mapped by Healy & Thompson (1964).

The volcanic domes which are prominent features within the Tauranga region are mostly ryholitic domes with some dacitic domes. There are five rhyolitic domes which fall in the Papamoa region and one dacitic dome.

A.1 Stratigraphy of the Tauranga Region

The oldest formation in the region is the Otawa Volcanics (2.95 – 2.54 Ma) which outcrop over 35km^2 in the Papamoa Ranges (Huges, 1993) and consist of volcanic breccias and andesite lavas. Hydrothermal alteration is evident in some places, with two major quartz veins which run parallel to the NNE striking fault mapped by (Healy & Thompson, 1964). The next unit is the Minden Rhyolite (2.12-2.18 Ma), which consists of widespread ignimbrites and rhyolitic lava domes and flow. It consists of four formations: Kaikaikaroro, Mt Maunganui, Mangatawa and Pukunui, which all have a number of rhyolitic domes. These Minden domes are the most prominent feature within the Tauranga Region (Briggs, et al., 1996). Briggs et al (1996) did note that although, mentioned above, it was thought that the domes in the East and West were aligned due to faulting no justifiable evidence of this was found. The Matakana Basalt (age unknown) occurs in a single lava flow off the Matakana Island and is the only location of basalt found in the Tauranga Region (Briggs, et al., 1996) It is yet to be dated, but is known to precede Te-Puna Ignimbrite and post-date the Minden Rhyolite. The Kopukairua Dacite is a poorly exposed (therefore not dated) single dome and flow dacite volcano complex situated in the Papamoa range (Briggs, et al., 1996).

The first of the Ignimbrite units is the Waiteariki Ignimbrite (2.18-2.13 Ma) which defines the Whakamarama Plateau. It is divided into three main sections; the base is non-welded and pumice rich, the middle section is a welded ignimbrite, with the upper section being a biotite bearing unit. The Waiteariki Ignimbrite is thought to form the basement of the Tauranga Basin to a maximum depth of 150m and is overlain by pyroclastic, fluvial and estuarine deposits of the Matua Subgroup (Briggs, et al., 1996). The Papamoa Ignimbrite (age unknown) is found to the northeast of the Tauranga regions and outcrops at the foothills of the Papamoa ranges where it forms a fan that dips gently to the north. It is divided into two sections; the upper and lower Papamoa Ignimbrites. The upper section consists of a single rhyodacite type and the lower section consists of one basic scoria and five acidic scoria types (Huges, 1993). The Ongatiti Ignimbrite (1.21 Ma) is a caldera forming ignimbrite and is the most voluminous unit to erupt from the Taupo Volcanic Zone (TVZ) (Briggs, et al., 1996). It is a partially densely welded pumice rich ignimbrite and overlies the Waiteariki Ignimbrite. It outcrops along the Wairoa River. The Te Puna Ignimbrite (>0.78 Ma) is a non-welded to partially welded brown ignimbrite. It is thought to be a small volume ignimbrite (<5km^2) and found in the vicinity of the Tauranga Harbour. The Te Ranga Ignimbrite is a grey non-welded sandy textured ignimbrite. It covers an area of about 30 km^2 but is considered a small volume ignimbrite (<5 km^2) with varying thickness from 6 – 25m. It overlies the Te Puna Ignimbrite and underlies the Waimakariri Ignimbrite. The Waimakariri Ignimbrite (age unknown) is a voluminous (up to 100 km^3) partially welded rhyolitic ignimbrite underlying the Mamaku Ignimbrite. It outcrops between the Wairoa River, where it is at its thickest (>40m), and east toward the Papamoa Range. It overlies the Waiteariki and Te Ranga ignimbrites. The Mamaku Ignimbrite, the youngest of the Ignimbrties is a pumice, crystal and lithic poor vapour phase altered welded ignimbrite with highly variable welding (Briggs, et al., 1996). It overlies the Waimakariri Ignimbrite to the South of the Tauranga region and partially covers the Papamoa Ranges as well as forming the upper surface of the Mamaku Plateau and dips 2° to the North (Briggs, et al., 1996).

The Matua Subgroup (c. 2 Ma – c. 50 ka) consists of a wide variety of lithologies which vary both laterally and vertically. The Matua subgroup includes all estuarine and terrestrial deposits that formed after the Waiteriki Ignimbrites (2.18 Ma) and before Hamilton Ash (0.35 Ma) deposits.

Terraces have formed, from these sediments, in number of locations in the region. The Pahoia Tephras, which are included in the Matua Subgroup, include all tephras older than Hamilton Ash Formation. These tephras are intercalated with the sediments of other formations within the Matua Subgroup. The Hamilton Ash Formation consists of highly weathered, clay textured tephra and paleosols which can be attributed to eruptions in the TVZ. It has been divided into eight units and is 2.5m at its thickest. The Rotoehu Ash is a widespread sequence of shower-bedded deposit derived from the TVZ. The Holocene and Late Pleistocene tephras consist of the Port-Rotoehu Tephras which consist of a number of tephras which blanket the Rotoehu Ash (Briggs, et al., 1996). The Holocene sediments comprise of tombolos which confine the Tauranga Harbour, and these are joined to the mainland by a series of progradational dunes which were formed during the Holocene (Briggs, et al., 1996).

The Waiteariki Ignimbrite forms the base of the Tauranga Basin, and minimal faulting has occurred since its deposition around 2 million years ago. The only faulting that was found in the basin is the two NNE striking faults which occur in the Papamoa ranges as mentioned above (Healy & Thompson, 1964). It is likely that deep seated faulting, which has been buried by sedimentary and pyroclastic deposits, control the alignment of other peaks in the region. The alignment of local volcanic vents, the NNE alignment of the Tauranga Harbour peninsula and the direction of the major rivers in the region is further potential evidence of these deep seated NNE faults (Briggs, et al., 1996).

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B. Appendix B: Additional Information

B.1 Factors Affecting Deformation

B.1.1 Stress

Araya (2011) reports on Thom and Brown's (1988) observation that material stiffness and resistance to permanent deformation increase with the fines content, which was also concluded by Uthus (2007). Henderson et al. (2011) identified an increase in resilient modulus as aggregate angularity and surface texture increases. It was also noted that moisture and high fines content reduce the resistance to permanent deformation.

Traffic loading causes plastic deformation, which increases over time (Gribble & Patrick, 2008). Henderson et al. (2011) associates the poor performance and failure of unbound pavements with an increase in plastic shear strength.

Rutting is a common pavement failure, in which deformation in the pavement layers can be identified (Fwa, et al., 2004). The majority of rutting, up to 70%, is caused by basecourse deformation (de Pont et al., 1999, Arnold et al., 2008; Chen, 1998). Huang (2004) agrees with de Pont et al, (1999) and states that the majority of pavement deformation occurs in the upper layers of the pavement, which is caused by an increase in traffic loading or ingress of water through thin surfacings.

Hossain (2010) investigated the mechanistic characterisation of subgrade soil and common basecourse aggregate from Virginia sources. Six aggregate sources, six fine soils and five coarse soils, were used. The samples were subjected to resilient modulus testing and quick shear (triaxial) testing. The results of the quick shear triaxial and resilient modulus correlated better than the California Bearing Ratio (CBR) test, which indicates that the quick shear triaxial tests can be used to estimate the resilient modulus of fine cohesive soil.

Patrick & Werkmeister (2010) investigated a range of densities (88-95% of MDD) and its effect on the construction of basecourse material. It was concluded that some post construction deformation on Greenfield pavements is inevitable when using standard New Zealand specifications and techniques. This was supported by RLT testing and finite modelling, although the degree of rutting would be relatively small (3mm of rut depth at 88% moisture). Compaction of the aggregate can result in degradation as Novak, Jr & Mainfort (1966) observed, specifically in the fractions passing the 3/8" (9.5mm) sieve.

B.1.2 Moisture Content

Bartley (1979) indicated that the two main reasons why pavements become unstable are excessive loading and water ingress. This indicates the importance of designing a road for the expected traffic and climatic conditions. A trial performed at the test track CAPTIF (Canterbury Accelerated Pavement Testing Indoor Facility) noted that no increase in pavement life was obtained when increasing the pavement depth, which further confirms the Arnold et al,(2008) finding that the deformation, resulting in rutting failures, occurs in the top 200mm of the pavement aggregate. Gribble & Patrick (2008) noted that pavement failure may be the result of substandard construction or inadequate specification, but were unclear as to which was the main contributing factor.

Saturation is a critical parameter that affects the basecourse performance and an essential parameter in the calculation of saturation is the voids percentage. Stevens & Salt (2011) express their concern of contradictory opinions and views on the calculation of voids in their literature review. The views regarding how voids should be calculated ranged from using apparent specific gravity to solid density and vary from person to person.

Arampamoorthy & Patrick (2010) researched the variables that relate to the performance of a pavement by studying four of New Zealand's state highway network of thin-surfaced granular pavements. None of the four networks investigated showed any relationship between pavement age and rut depth or roughness. Statistical methods can be used to establish the failure risk associated with a pavement, but limited analysis has been conducted on comparing results with in-service pavements (Arampamoorthy & Patrick, 2010). Patrick (2009) reported that pavements may fail due to water being pushed through the seal from heavily vehicles. From this research Arampamoorthy & Patrick (2010) determined that thin-surfaced granular pavements have a bimodal distribution of life, where shallow failures and potholing occur in the first few years of the design life and the pavement then reaches a stabilised state.

B.1.3 Number of Load Applications

Uzan (2004) presented a mechanistic- empirical framework for evaluating permanent deformation in flexible pavements to be used as an analysis tool in addition to the design method. Two material properties were required, which were the stress-dependent modulus of the pavement and the relationship between the accumulated and resilient strain over the number of load cycles, and the stress level. From these investigations he determined that permanent deformation consists of two components, consolidation and shear. The degree of compaction required by each layer of unbound pavements takes into consideration the consolidation and the shear component which occurs only in the subgrade of the pavement and is addressed by the design of the pavement. Uzan (2004) concluded that the effect of permanent deformation is the result of repeated load on a material which is perfectly elastic.

Siripun et al. (2010) reported on the permanent deformation of a crushed rock base (CRB) by applying the shakedown concept, three ranges of permanent deformation (mm) response under repeated loading (N), to develop a model of permanent deformation for pavement analysis in Western Australia (WA). Samples were compacted at 100% of MDD and 100% optimum moisture content, and underwent repeat load triaxial tests at different stress levels to mimic the repeated cyclic loads of traffic. Siripun et al. (2010) define the factors contributing to permanent deformation as the stresses, both vertical and horizontal, from the vehicle wheel load. As these stresses increase beyond the limitations of the material, expressed in Range C, the plastic elements within the pavement will strain causing permanent deformation (rutting).

The shakedown theory consists of three stages of permanent deformation under repeat loading (Siripun, et al., 2010);

1. Plastic shakedown range (Range A)

   The loading level is applied below the plastic creep range (Range B). The material responds at high strain rates with a low number of repeated cycles and is entirely plastic. Once the material reaches a stable state the deformation is completely resilient and no permanent deformation develops.
2. Plastic creep range (Range B)

   The loading level is low enough to avoid incremental collapse. The material will reach a stable state with an increased accumulation of plastic strain. If repeated loading is continued, failure will occur.
3. Incremental collapse range

   Plastic strain accumulates rapidly as the loading level is high and failure occurs after a small number of repeated loading cycles. The material stiffens initially before failure occurs.

From his research, Bartley (2007) concluded that a coarser grained particle was best for resisting permanent deformation, except in cases of high fines content with dry material. The resilient modulus will increase as the fines content increases due to finer material filling voids in the basecourse.

Henderson et al. (2011) and Araya (2011) emphasise the importance of aggregate gradings, as the ultimate performance of the pavement relies on the particle to particle interaction. Gradings are particularly important as basecourse layers with a grading of n=0.6 resulted in a greater susceptibility to rutting (Gribble & Patrick, 2008).

From the aforementioned research it becomes clear that there are several important mechanisms that contribute to pavement performance. The research also places a great deal of emphasis on the fines content; this affects saturation content, voids and gradings. Adopting stricter grading controls than current controls may enable the identification of other problem areas in an effort to improve the overall pavement performance can be increased.

B.2 Smectite Clays

Different clays, particularly smectites have different swelling capacities under a number of conditions. Laird, (2006) investigated the six processes that control the swelling of smectities and can be simplified and are described;

1. Crystalline swelling occurs between the smectite layers and the magnitude of swelling decreases with the increase in layer charge.
2. Double-layer swelling occurs between quasicrystals (quasicrystals are a collection of layers stacked together and can be any number from two to thousands of layers), but is not effected by layer charge
3. Formation and breakup of quasicrystals occurs when the double layer repulsion is over come as the quasicrystal is enlarged. This causes two quasicrystals to fuse together. External factors such as shaking and stirring can cause a quasicrystal to break up. The larger the quasicrystal the higher the layer charge and the more stable it becomes, this breakup and formation is yet to be investigated further. It can be deduced that the larger the crystal the more stable it becomes and it's swelling potential decreases. A reversal of these characteristics for smaller quasicrystals.
4. Cation demixing is a process by which the exchangeable cations on the surface of the smectite will cause the breakup of the quasicrystal when in contact with distilled water.

When two cations are present in the aqueous system the smectite may exhibit a preference of one cation over another. This causes the one cation to segregate into certain layers and the opposing cation into other layers, when kinetic energy is introduced in to the system, such as shaking the quasicrystals break apart which increases the swelling capacity.

5. Co-volume swelling is a process by which water molecules are consistently colliding with particles in a solution and therefore these particles are in constant motion. The first interaction between two freely moving smectite layers will be repulsion causing a rotation. This rotation coupled with the rotation of the particles in the solution will determine the rotational co-volume. No research has been conducted on layer charge and co-volume swelling but Laird, 92006) assumes that it'll be inversly realted to layer charge.
6. Brownian swelling is also entropy driven process where the layers of the crystal are dispersed so widely that there is no interaction between them.

These processes can act singularly or coupled with any of the others which change the swelling capacity of the smectite clay. Another factor affecting the breakdown of a rock due to swelling clays is the accumulations of the clays as well as the permeability of the rock. if more water or ethylene glycol can interact with a high concentration of clay, the more likely it is that the rock will break down.

Glassman (1982) studied andesite cobbles found in a wet soil environment and identified smectite as an intermediate product or a dominant secondary phase, which most likely formed within the cobbles due to a wet environment with minimal drainage. The smectites that Glassman (1982) identified formed within the lithic fragment by the initial transformation of plagioclase, and from the alteration of interstitial glass.

Houston & Smith (1997) developed a Smectite Alteration Index (SAI) which measures the degree of smectite alteration within a mineral. This was initiated due to road failures attributed to basalt aggregate breakdown and the presence of alteration and secondary phase minerals within the basalt. Smectite alteration was identified via rapid X-ray Diffraction (XRD) analysis, which provided a clearer representation of deleterious minerals. Cole and Sandy (1980) cite a study by Van Atta and Ludowise (1976) that indicates that smectite, an expandable clay mineral, when exposed to excessive loading and moisture, is prone to degradation and therefore is responsible for aggregate breakdown. Hudec et al. (2008) noted that the breakdown of aggregate increases the plastic fines content.

Houston and Smith (1997) found that thinner basalt flows contained a higher percentage of interstitial glass and therefore were more susceptible to smectite alteration. They also found that the distribution of smectite clays is a result of the distribution of glass within the flow.

Hudec et al. (2008) identified devitrified volcanic glass within the PLQ aggregate, which as mentioned above, has the potential to rapidly degrade to smectite clays. The montmorillonite found within the PLQ rock were sodium- rich, so these smectites respond to calcium treatment due to the cation exchange between the sodium (Na) and calcium (Ca).

The smectite identification technique was developed by Dr C.C. Harvey for the use on New Zeeland's Wairakei Geothermal Field and used as a Smectite identification tool (Rosenberg, 2012). The test is exclusive to identifying smectite clays as smectites have a high cation exchange and response to Methylene Blue compared with other clays (Rosenberg, 2012). The report goes on to cite Czimerovaa et al. (2006), who explain that smectite exchange capacity is approximately 100 meq/100g which equates to 1% smectite to 1ml of methylene blue. The detailed method can be found in Appendix C.

B.3 G1 Crushed Stone

G1 crushed stone is a basecourse material with very tight construction and grading specifications. It was developed in South Africa in the 1950's from a single stage crusher-run material, and in the 1980's it was fully developed. When used in pavements appropriately, it can withstand a bearing capacity of up to 50 million standard axles (MISA). It was developed after engineers on a site noticed that after heavy rainfall the material expels fines and the aggregate binds together forming a strong pavement base. Reverse engineering, where this pavement was analysed after construction to determine the required properties, was utilised to develop the G1 crushed stone where damp material is gently placed onto a strong level subbase. The moisture content of the material is crucial for accurate compaction. The G1 crushed stone is then rolled a number of times, left to stabilise, and then doused with water and rolled again for compaction. Due to strict condition requirements for the use of G1 crushed stone a number of important criteria must be met in order to achieve the pavement specifications. Kleyn (2012) outlines these requirements as follows;

- The aggregate fraction must be such that the material interlocks to form a matrix similar to that of the intact parent rock and form a "solid density". This final state has a density much higher than usually produced and therefore must be expressed as a Solid Relative Density (SRD). At 88% SRD, the target density, the equivalent Mod AASHTO density would be 106%. This cannot be directly related back to MDD as the methods are slightly different, but as both target the MDD of the material the values should be similar if not the same.
- The particle grading is very important and must conform to the Fuller grading curve which uses the Talbot equation (Equation 1) to determine the n value. The grading needs to provide enough of each particle size to fill all the inter particle voids. For construction and compaction requirements the largest aggregate size was set at 37.5mm. The fines grading should meet an n-value of 0.3 and the coarser fraction an n-value of 0.5.
- The aggregate needs to be able to withstand general construction practices and not have any inferior qualities. Only un-weathered fresh rock should be used and no inclusions of fines from other sources must be used.
- The plasticity of the G1 stone needs to be as close to zero as possible; this is to minimise any factors that may negatively affect the particle interlock, and this includes any material that is

sensitive to moisture. It is specifically noted that material containing smectites should be avoided.

- The subbase must be compacted to C4 standard (750-1500 kPa UCS) to withstand the large volume of water that the subbase will be exposed to during compaction.

The benefits of this design are multiple, but due to the strict requirements and controls in the aggregate gradings and construction the design limits the source of material used. Although some aggregates may not be suitable for G1 crushed stone, the design idea is an example of how to adjust an aggregate "mix" to provide an enhanced quality product.

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C. Appendix C: Specification Review

C.1 Current M/4 Specification

C.2 Source Property Testing

Source Property testing allows for the characteristics and properties of the rock to be determined and lists three test methods to be adhered to. This ensures that the source of the aggregate is adequate and will perform to the necessary standard. The following tests are included;

- Crushing Resistance
- Weathering Quality Index
- California Bearing Ratio

Crushing Resistance is tested according to NZS 4407:1994 Test 3.10, *The Crushing Resistance Test.* It is used to determine the processing strength of the aggregate and the possibility of deterioration. Weathering Quality Index is tested according to NZS 4407:1991 Test 3.11 *Weathering Quality Index Test,* and is used to test the aggregate under a number of accelerated conditions, including boiling, ambient temperatures, drying under heat and saturation which will give an indication of its durability.

California Bearing Ratio (CBR) measures the load bearing capacity of a soil used in road construction, and can be tested in situ or in a laboratory. The sample is compacted according to NZS 4402: 1986, Test 4.1.3 *New Zealand Vibrating Hammer Compaction Test at Optimum Water Content* and tested in accordance with NZS 4407: 1991, Test 3.15 *The California Bearing Ratio Test*. It was developed by the California State Highway Department around 1930, and it is used to determine the basecource resistance to deformation.

C.2.1 Production Property Testing

Production property testing ensures the processing of the aggregate into M/4 basecourse is appropriate, and that properties of the basecourse are tests to ensure it will perform in application. Production testing gives an indication of how the material is affected by the processing and variations of handling, they include;

- Quality of Fines
  - Sand Equivalent
  - Clay Index
  - Plasticity Index
- Broken Face Content
- Particle Size Distribution

The Quality of Fines requirement stated in the M/4 (2006) specifies that the aggregate must comply with at least one of the three tests required: Sand Equivalent test, Clay Index (CI) or Plasticity Index (PI).

A Sand Equivalent (SE) test requires samples to be tested according to NZS 4407: 1991, Test 3.6 Sand Equivalent Test. It is a rapid test which displays the ratio of sand to fines in an aggregate mix. This is especially important as excessive fines in an aggregate mix can cause pavement failure. The SE shall not be less than 40. It was developed by Hveem in 1953 and in 1955 O'Hara applied the test to the 4.75 mm fraction and discovered a correlation between the SE and Plasticity Index (PI) and fines percentage less than 75µm (Lowe et al, 2009). The benefits of the test include the ease of application, as it can be conducted out in the field and is inexpensive, and results are relatively quick to establish (Lowe, 2009).

Atterberg limits are used to determine the PI and CI to classify cohesive soils. These are usually performed on the fines (the PI test requires material passing the 425 µm to be test and the CI requires the material passing the 75 µm sieve to be tested) from the aggregate samples once grading is completed. The PI and CI are tested in accordance with NZS 4407: 1991, Test 3.4 *Plasticity Index Test and* NZS 4407: 1991, Test 3.5 *Clay Index Test.* These results give an indication of the strength and settlement of the soils (Holtz, et al., 1981).

The PI gives an indication of the complete plastic state of a soil including liquid limit and plastic limit. It was derived from the commonly known Atterberg Limits, developed by Albert Atterberg in the early 1900's. It involves the determination of three states of the sample (passing a 425 µm sieve), known as Plastic Limit (PL) where a 3mm thread is rolled, Liquid Limit (LL) is determined when the samples begins to behave in a liquid type form, and Plasticity Index (PI) is calculated using the results from the PL and LL and the following equation (Equation 3):

$$\text{Plasticity Index} = \text{Liquid Limit} - \text{Plastic Limit}$$

The CI test reveals the presence in the aggregate of any reactive (expansive) clay. The Clay Index test was originally developed by Jones in 1967, and was adapted by Sameshima for use in New Zealand. The test uses Methylene Blue and measures how much is absorbed onto the surface of the fines fraction (Lowe et al, 2009).

The Broken Face Content test requires two or more freshly broken faces of a sample coarser than the 4.75mm sieve and that each of the three aggregate fractions between 37.5mm and 4.75mm shall not be less than 70% broken faces. It is tested in accordance with the NZS 4407: 1991, Test 3.14 Broken Face Test. Figure C.1 displays the difference between the PLQ aggregate and Canterbury greywacke after crushing. The Canterbury greywacke is an alluvial gravel and has rounded faces whereas the PLQ aggregate is from a hard rock quarry and all the faces are freshly exposed.

Figure C.1 Broken faces comparison. A. displays the broken faces from the PLQ hard rock quarry. B. displays the broken faces from the Canterbury greywacke control stone. Note how the Canterbury greywacke has some pieces with rounded edges. These rounded edges are not classified as broken faces

The Particle Size Distribution (PSD) test requires the sample to be graded in accordance with NZS 4407: 1991, Test 3.8.1 *Wet Sieving Test*. The particle size and distribution are important factors in the pavement performance as the larger stones provide structural strength and the finer particles fill the voids creating a flexible pavement. Table C.1 shows the minimum and maximum percentage of particles allowed to pass through each fraction size.

Table C.1. Current specification (TNX M/4 2006) Particle Size Distribution maximum and minimum allowable percentages of weight passing each fraction size

Test Sieve Aperture	Maximum and Minimum Allowable Percentage Weight Passing
	AP40 (Max size 40mm)
37.5mm	100
19mm	66 - 81
9.5mm	43 - 57
4.75mm	28 - 43
2.36mm	19 - 33
1.18mm	12 -25
600µm	7 -19
300µm	3 -14
150µm	0 - 10
75µm	0 - 7

C.3 Limitations

NZ roads are designed using an empirical method whereas the testing is completed mechanically, and it is difficult to find an accurate representation or correlation with the results and performance of roading pavements. However, commonly acknowledged with all the tests that the competency, skill and knowledge of the technicians greatly affects the outcome of the results. The limitations of these tests include, but are not exclusive to the following;

Sand Equivalent test does not give a direct measure of clays or deleterious minerals and is merely an indication tool to measure the fines in the silt and clay range, this can lead to unsuitable material being classed as suitable and visa-versa. Although the clay index test refers to clays within the material, it does not distinguish between the type of clays and the amount within the sample. The CI test is often focused around the identification of smectite clays, but the methylene blue responds to other clays minerals and can give a false representation of the clay content. Any substance that has the capacity for cation exchange will absorb the methylene blue, whether they are deleterious minerals or not. Therefore it can be concluded that there is a probability for a sample to reveal a high CI value, but in fact have little to no clay minerals present (Lowe et al, 2009). The most prevalent limitation to the PI is the competency of the technician; because PI value can still be obtained even if the sample is non-plastic.

In 2012 CETANZ (Civil Engineering Testing Association of New Zealand) conducted an investigation into the variability of results between laboratories, and the result obtained from a Weathering Quality Index (WQI) test. The report identified the following factors as indicators as to why the variability occurs (CETANZ, 2012);

- Method of rolling
- Sample preparation
- Treatment of water at each stage of the test
- Boiling of the water

- Uncertainty of measurement of Cleanness Value Test

The in-field and laboratory methods used for the California Bearing Ratio test differ; some comparison can be made between the two tests only if a similar method is followed.

C.4 NZTA M/4 Draft Specification Review

C.4.1 Background

This section details the changes and additions made to the TNZ M/4 standard, and draws a comparison between the current standard and the proposed NZTA M/4 2012 standard. Included is an indication of the effects of this proposed standard on the suitability of PLQ basecourse, and of PLQ as a preferred supplier. Research has been initiated to establish a more suitable standard for basecourse aggregate which will be dictated by traffic loads, i.e. higher traffic loads will require stricter or tighter requirements (Stevens & Salt, 2011). Based on this research, NTZA composed a new, draft version of the Specification for Basecourse Aggregate, which is yet to be released (NZTA, 2012). The reasoning behind the additions and changes is documented in NZTA research report 459 (Stevens & Salt, 2011); as it was found that basecourse with a high degree of saturation was gap graded in the sand fraction. Although the current standard does limit the amount of gap grading through grading controls, it was recommended that tighter restrictions be introduced. This research is also covered in the sand grading exponent and grading shape control sections. Amendments made in the draft specification have not been exclusive to the addition of the gap-grading control; other sections have been modified to allow for improved testing and ultimately higher quality aggregate production. The following is a summary of the standard tests required in the draft M/4(2012) proposed standard.

C.4.2 Source Property Testing - Proposed additions and potential changes;

Crushing resistance: any aggregate which includes blended fines from another source must undergo additional assessment, or have documentation of pervious performance confirming the quality of the aggregate. This requirement was added as the additional fines durability would not be reflected by the fines range used in the crushing resistance test. Aggregate with a crushing resistance less than 130 kN may be used as a basecourse depending on the Equivalent Standard Axle (ESA) loading conditions (Stevens & Salt, 2011).

Sampling: sampling of aggregates will be conducted no more than three months prior to performance testing (source property and production property testing), unless documentation of appropriate stockpile management is provided and the engineer is satisfied with the material. Sampling of the PLQ aggregate is generally conducted days after production as the laboratory is on site and logistical delays are minimal.

C.4.3 Production Property Testing - possible additions and potential changes;

The Quality of Fines standard in the current M/4 specification requires the material to comply with either the Sand Equivalent, the Clay Index (CI) or the Plasticity Index (PI). However, the proposed draft specification would require the material to comply with at least two of the four fines criteria, with the additional criteria being Sand Grading Exponent. In the draft specification, the PI and CI test would require some changes that are outlined below:

Weighted Clay Index: the CI of the basecourse passing the 75 µm sieve multiplied by the percentage passing the 75 µm sieve shall not exceed 15 (current requirements state the fraction passing the sieve shall not exceed 3 and is not governed by the percent of material passing that sieve). The NZS 4407: 1991, 3.8.1 *Wet Sieving Test* is added to the requirements as it is needed for the calculation. The result of percentage passing the required sieve is to be expressed to two significant figures (sf). In most cases the weighted CI grading will be conducted when the Particle Size Distribution (PSD) grading is completed.

The Weighted Plasticity Index requirement states that the PI of the basecourse passing the 425 µm sieve multiplied by the percentage passing the 425 µm sieved shall not exceed 40 (current specification states that PI shall not exceed 5 and is not dependant on the percentage passing the 425µm sieve). This requires an additional grading or the inclusion of the fraction size (425 µm) in the PSD test or the result to be calculated using the values of the sieves above and below. The test method Test 3.8.1 *Wet Sieving Test* is added to the requirements with the percentage passing expressed in two significant figures (sf).

The Sand Grading Exponent (SGE) is an additional requirement included in the draft M/4 (NZTA, 2012) specification testing and will be conducted in accordance with test method NZS 4407: 1991, Test 3.8.1 *Wet Sieving Test*. Although it is not required at the time of writing, (i.e. it's not in the current standard specification but will be included in the revised draft specification) the test will be included in the requirement for the analysis of samples to assess whether the material can meet these standards.

The Sand Grading Exponent (SGE) is tested according to NZS 4407: 1991 Test 3.8.1 *Wet Sieving Test* and shall not be less than 0.40. It measures the amount of gap grading and is the effective slope of the particle distribution in the sand size range. It was introduced to identify aggregate that is more of a gap-graded silty gravel rather than a well graded sandy gravel. The SGE applies to the overall grading shape (Table 3.2) and ensures, with the PSD, that the M/4 basecourse is a well graded sandy gravel and removes the potential for a gap-graded silty gravel. It is determined by the two lowest percentages in the sand range. Basecourse materials which have previously performed poorly have shown either an excessive fines content or gap grading between the 0.15mm and 475mm fractions; this may be associated with hard rock quarries and the extraction process causing angular material and increased silts (Stevens & Salt, 2011). The gap grading between the fractions, in addition to those basecourses with an n-value less than 0.40, causes instability within the pavement as insufficient sand particles means there is less point to point contact within the mix, which in turn affects the shear stability (Stevens & Salt, 2011).The evidence of many poorly performing basecourse aggregates can be related back to the gap grading and sand grading exponent (Stevens & Salt, 2011). If the SGE is less than 0.40, additional testing or previous historic reports will be required to ensure the basecourse will perform adequately.

This addition was investigated in 2013 by Fulton Hogan where 1917 test results were extracted from the laboratories management system – Qestlab and the SGE was calculated. It was found that 815 tests failed to meet the required 0.40 minimum and that the majority of the results fell between 0.35 and 0.40. It was further investigated to determine if any of the critical ranges used in the SGE calculation was a contributing factor in the failures; it was concluded that the distribution between the ranges were very similar indicating the failures could be the result of a combination of all the ranges. It was suggested that because 25% feel between 0.35 and 0.40 and no particular range could be attributed to the failures, that the requirements be relaxed to a minimum of 0.35. If the 0.40 standard was held a large number of material samples would be fail and ultimately be rejected.

The Broken Faces content of aggregate in fractions coarser than 4.75mm shall not be less than 70%, compared to the current specification that states that each of the three aggregate fractions between 37.5mm and 4.75mm shall not be less than 70%. Due to the nature of PLQ and the quarrying process, all material has broken faces and will meet this requirement.

PSD additions and changes include that the particle distribution will conform to the changed incremental grading exponent in Table C.2 Maximum allowable percentages of weight passing the sieves between 600µm - 9.5mm were increased slightly and all other values remained the same. Table 8.2 presents the percentages for the proposed specification;

Table C.2 Maximum allowable percentage of weight passing test sieve. Taken from NZTA (2012)

Test Sieve Aperture	Maximum and Minimum Allowable Percentage Weight Passing
	AP40 (Max size 40mm)
37.5mm	100
19mm	66 - 81
9.5mm	43 - 62
4.75mm	28 - 49
2.36mm	19 - 38
1.18mm	12 - 29
600µm	7.0 - 21
300µm	3.0 - 14
150µm	0.0 - 10
75µm	0.0 – 7.0

The Grading Shape Control specification will be expressed as the lower limit governing shear stability and the upper limit governing segregation and compactability (Stevens & Salt, 2011). After communication with Norm Major, Steven & Salt (2011) reported that the grading shape control was originally implemented 40 years ago. It was concluded that this was based on experience and judgement only with little, or no, study involved. After some years of research, grading shape control now is imperative in establishing basecourse suitability and Steven & Salt (2011) recommended stricter controls should be introduced. The current standard allows for a large variance of n-values between 0.2 and 1.2 over the nominated sieve size. The n-value is not required to be reported in the current M/4 specification, and is often not calculated. As discussed in the Sand Grading Exponent section above, this poses a particular risk to the performance of the basecourse, as the literature suggests any fractions within the sand range with an n-value less than 0.4 are likely to perform poorly (Stevens & Salt, 2011). A grading exponent of two sieve sizes is displayed in Figure C.2, with typical maximum and minimum values from the inventory covered by Steven and Salt (2011). This shows that the grading exponent can be restricted between to 0.3 and 1.0 and will encompass most basecourses.

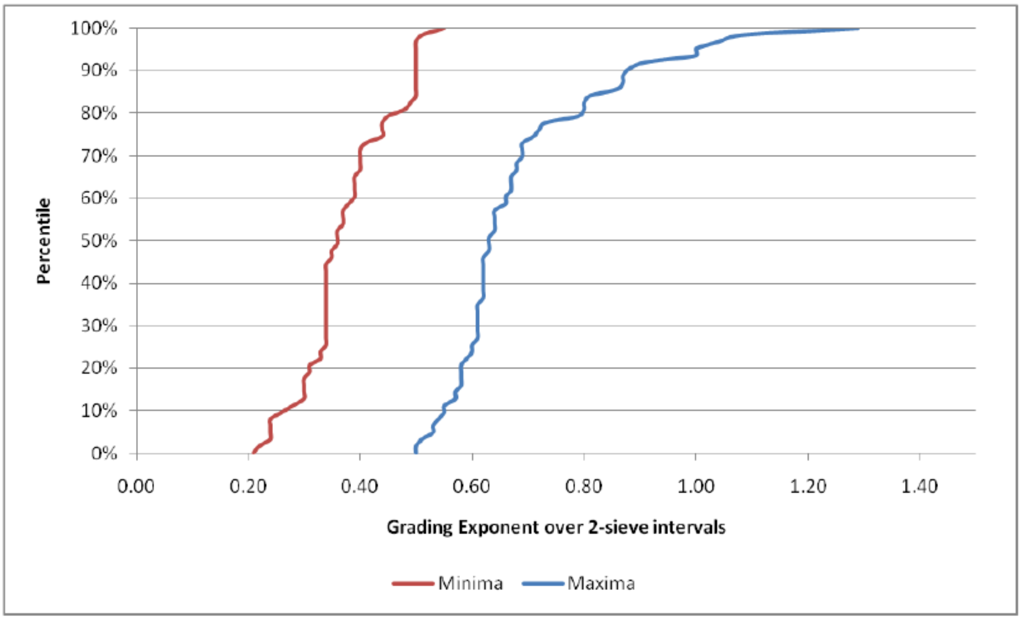

Figure C.2 Grading Exponent over two sieves for most basecourses. Extracted from (Stevens & Salt, 2011).

These findings prompted the tightening of the limits as shown in Table C.3, Steven and Salt (2011) suggest narrowing the limits for materials which have high quality standards and can be relaxed for those with lower standards. Steven & Salt (2011) mention that material which has a grading exponent less than 0.4 will have insufficient particles of that fraction, whereas in material with a grading exponents above 0.7 there will be excessive particles of that size.

Table C.3 Incremental grading exponent taken from NZTA (2012).

Incremental size range	Incremental grading exponent (n-value) for each combination of sieve sizes	
	Maximum	**Minimum**
19 mm – 4.75 mm **9.5 mm – 2.36 mm** **4.75 mm – 1.18 µm** **2.36 mm – 600 µm** **1.18 mm – 300 µm** **600 µm – 150 µm**	1.0	0.3
Note: The criteria apply for every combination of 2 standard sieve size increments where the percentage passing is > 0% and < 100%		

AP30 Particle distribution envelopes have been included into the draft M/4 specification and an additional Recycled Crushed Concrete (RCC) test with a crushing resistance of 110kN was introduced; the 130kN RCC crushing resistance test at 130kN is still detailed in the proposed draft specification

C.5 References

CETANZ. (2012). *Weathering Quality Index of Coarse Aggregate.* Wellington: CETANZ.

Holtz, Kovaks, & Sheahan . (1981). *Introduction to Geotechnical Engineering.* New Jersey: Prentice-Hall Inc.

NZTA. (2012). *Draft Specfication for Basecourse Aggregate.* Wellington: New Zealand Transport Agency.

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TNZ M/4 N. (2006). *NOTES TO THE SPECIFICATION FOR BASECOURSE AGGREGATE.* Wellington: Transit NeW Zealand.

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D. Appendix D: Test Methods

D.1 Crushing Resistance

Crushing Resistance samples were wet sieved on site at PLQ, the 9.5 mm - 13.2 mm fraction was retained and bagged wet to be sent to Christchurch. On arrival in Christchurch the bags were re-sieved over the 9.5 mm fraction then washed and dried in a 110°C for testing. The Crushing Resistance mould was wiped with a dry cloth before use and tarred on balance. Roughly 3 kg was obtained for the test. The material was placed into the mould in three equal lifts, and at each lift the material was prodded with a tamping rod 25 times. A plunger lid is placed on the top; the mould is sufficiently filled when the plunger surface lies flush with the mould surface. It is then placed into the testing machine for testing. A CONTROL Pilot 4 automatic compression machine was used to apply the load (Figure D.1).

Figure D.1 CONTROL Pilot 4 automatic compression machine used in the testing of aggregates for crushing resistance

The specification requires that 130kN of load be applied to the material in 10 minutes. For this test speed was set 217N/s to achieve the require load over the specified time. At every minute the kN are recorded to ensure the load is reached within the required time frame. On completion of the load application the sample is removed and sieved over a 2.36mm sieve. These fines collected are calculated as a percentage of the original mass of the sample placed in the mould. If the fines remain below 10% then the material has passed the testing.

D.2 Weathering Quality Index

The material for the weathering quality index was washed and prepared at the PLQ laboratory. The samples were divided and bagged (air tight sealed) into the two size fractions needed or the test; material retained on the 9.5 mm and 4.75 mm sieve. On arrival in Christchurch six samples were randomly selected for the first round of testing. Each sample comprised of 2 kg of the larger material (9.5mm) and 3 kg of the smaller material (4.75mm). They were placed into a metal tray and mixed to ensure even distribution of the particle sizes. The samples were covered with distilled water and left to soak for 18 hours. On completion of the soaking the samples were drained (retaining the water in a clean bucket) and dried in a 110°C oven for four hours. The tray was removed from the oven cooled at ambient temperature for an hour and a half. Following cooling the sample was levelled and then rolled with a steel roller 50 times as the roller only covered half of the tray the rolling would be repeated for the second half. The tray was then turned 90° and rolled again completely the 50 rolls in each section. One roll was considered a full back and forth motion. The process was repeated ten times. When the last rolling was completed the sample (material and water) was transferred to a weighed metal flask. Distilled water was added until the water quantity was 3 kg. The flask was closed with a loose fitting lid and transferred to a hot plate, where it was boiled for one hour. The flask was then transferred to a sink where the water level was raised by inserting a pipe into the plug, or the flask was placed in a bowl in a sink. This ensured cool water was continuous added to around the flask. A thermometer was placed into the flask to measure the temperate drop. It had to drop to 40°C within 15 minutes. The flask was removed from the water and dried, the water content lost in the boiling process was added and the lid was securely fastened. The flask was inverted 50 times within 100s. The water was then immediately poured over a 4.75mm sieve and then over a 75 μm sieve where the material passing was collected into a bowl. This water was used to determine a Cleanness Value. The remaining larger samples obtained in the 4.75mm was washed a re-sieved, then placed in a 110°C oven over night to dry. Once dried the material was re-sieved and then weighed to record the percentage retained on the 4.75 mm sieve.

D.3 California Bearing Ratio

The CBR material was wet sieved over a 19 mm sieve on site at the PLQ laboratory. Each sample contained all material passing the 19 mm sieve and was sealed in a plastic bag and transported to the Christchurch laboratory. The moisture was corrected to 6.5% for each sample this was deemed the optimum moisture content (OMC). Samples were then compacted in three lifts according to NZS 4402: 1986, Test 4.1.3 *New Zealand Vibrating Hammer Compaction Test at Optimum Water Content.* The samples are covered by a filter paper and then soaked in a water bath for 5 days. On completion of the soaking the swelling reading was measured and tested to NZS 4407: 1991, Test 3.15 *The California Bearing Ratio Test.*

D.4 Quality of Fines

D.4.1 Sand Equivalent

The samples is tested in accordance with the NZS 4407: 1991, Test 3.6 *Sand Equivalent Test.* The measured sample, passing the 4.75 mm sieve is poured into a cylinder. The cylinder is filled with a calcium chloride flocculent solution, then shaken to ensure all particles completely separated. The cylinder is left for 20 minutes and two readings are taken. One being the height of the sand layer the other the height of the fines layer. The sand equivalent is expressed as a ratio using the following equation (Equation 4);

$$SE = \frac{Sand\ reading}{Clay\ reading} x100$$

D.4.2 Clay Index

The sample is tested in accordance with *NZS 4407: 1991, Test 3.5 Clay Index Test.* The sample is air dried and the sieved over the 75 µm sieve to obtain a 2 g sample (split from 8 g). The methylene blue is formulated to a 4.50 g/L concentration. The 2 g samples is diluted with distilled water, placed in an ultrasonic bath for 30 min and then left to stand for 1 min. 1 ml of the methylene blue is added to the burette every 30 seconds. After adding each drop the burette is shaken and a drop test is conducted. The drop test requires a single drop of the solution to be placed onto a filter paper via a glass rod. This is repeated until a blue halo is visible. If not halo is visible 1 ml of methylene blue is added to the burette as described above. The initial and final reading of methylene blue is recorded. The burette is left to stand for 30 min before back titration can commence. The original solution is placed into a clean burette with an equal amount of distilled water. Two more flasks are prepared with the solution in them and these are colour compared until equal. The CI results is calculated using the following formula (Equation 5);

$$CI=\frac{C-F}{2}$$

C= volume of methylene blue titrated

F= volume of methylene blue in back titration

CI= volume in ml of methylene blue solution adsorbed by 1 g of material

D.4.3 Plasticity Index

The PI is obtained following the NZS 4407: 1991, Test 3.4 *Plasticity Index Test.* All material passing the 425µm sieve is retained and the correct moisture is achieved (Figure D.2). The sample is mixed well to ensure an even moisture distribution (Figure D.3). The cone penetration test is conducted first. The same is placed into a cylinder and a cone is dropped into the sample for 5 seconds (this was automated). Two readings are taken with no more than 0.5 difference between them, otherwise a

3rd reading is taken. Roughly 10g is removed from the mould after each cone penetration reading and placed in a tin to record the moisture content.

A half an egg seized sample is manipulated using body heat until cracks appear around the edges. 2 samples of 10g each are taken and weighed. These are then rolled into threads of 6mm in diameter until it shears longitudinally and transversely. These are then weighed and dried to determine plastic limit. These results are then used to calculate the PI.

Figure D.2 Preparing the sample to obtain fraction passing the 4.25 μm sieve

Figure D.3 Plasticity Index sample prepared and mixed to obtain correct moisture content

D.5 Broken Face Content

The sample is tested in accordance with NZS 4407: 1991, Test 3.14 Broken Face Test. Three sieve sizes are used for this test and the minimum measured weight for each fraction is separated out. The fractions include 37.5 mm - 19.0 mm, 19.0 mm – 9.5 mm and 9.5 mm – 4.75 mm. The material for each fraction is washed and dried in an oven. The clean aggregate (of each fraction) is weighed and then separated from those with two or more broken faces and those pieces without. The collection of two or more broken faces is weighed as “weight of fractured aggregate”. The following calculation is used to determine the percent of particles with two or more broken faces (Equation 6);

$$\text{Percent of particles with two or more broken faces} = \frac{weight\ of\ fractured\ aggregate}{total\ weight\ of\ specimen}\ x\ 100$$

This is repeated for each fraction size.

D.6 Particle Size Distribution

Each sample was tested in accordance with the NZS 4407: 1991, Test 3.8.1 *Wet Sieving Test.* A quarter sample is collected and oven dried. The sample is then quartered again to the correct mass and then sieved through a collection of sieves (37.5mm, 19mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 600µm, 300µm, 150µm, 75µm). On completion the material retained for each fraction is weighed. This is then calculated into percentage passing. These results need to conform to the aggregate envelope defined in the TNZ M/4 (2006).

D.7 Indirect Tensile Strength (ITS)

The ITS sample is quartered appropriately and then the moisture is corrected accordingly. If water is added to the sample it is left in an air tight bag over night to allow for the moisture to permeate into the stone pieces. The blocks are prepared by removing the oversized fraction of the whole above 26.6mm and then separating the remaining fraction into that retained on the 13.2mm and that passing the 13.2mm. The ratios are determined for each fraction size and then added to make up a predetermined weight. This will allow for the accurate height of the specimen blocks after compaction. Cement was added in differing concentrations and was included into the fines proportion by replacing that percentage of fines (passing the 13.2mm sieve). The fractions were mixed together added by their appropriate ratio. The block specimens were compacted in a brass mould using a vibrating hammer into three layers for three minutes each. The blocks were left over night at room temperature to allow for some curing. They were then removed from the mould and the heights and weights were recorded. Then placed into an airtight bag and allowed to cure in a 40°C oven for 72 hours (3 days). On completion of this the samples were placed into a water bath overnight. Once removed from the water bath the wet saturated weight was recorded and placed onto the Humbolt for testing. A load was applied at 1.0 ±0.1 mm/min. immediately after testing the sample was broken up and placed in an oven to record a moisture reading. The ITS is calculated as follows (Equation 7);

$$ITS = 10^6 x(2 \times P) / (\pi \times h \times d)$$

Where	ITS	=	indirect tensile strength	[kPa]
	P	=	maximum applied load	[kN]
	h	=	average height of the test specimen	[mm]
	d	=	diameter of the test specimen	[mm]

D.8 Smectite Identification on Crushed Material

This test method was developed to allow for rapid testing in the field by Dr C.C. Harvey using New Zealand aggregate. The method is very similar to that of the Clay Index test. The method is similar to that of the Clay Index text but differs to allow for ease of application on site.

Rock is thoroughly cleaned and dried (oven temperatures vary between 40°C and 60°C depending on the depth the rock was collected). The rock is crushed by pestle and mortar and then sieved over a

125 µm sieve (coarser fraction to the CI test). 1g of the crushed rock is added to a conical beaker and 10ml of distilled water is added, followed by 1ml of sulphuric acid. The flask containing the sample is heated until boil and then left to cool for a minute. 1mL of methylene blue (3.74 g/l – weaker concentration than CI test) is added and stirred. Using a glass rod the sample is collected and dropped on a piece of filter paper and recorded and "count one", another 1ml of methylene blue is added, stirrer and dotted onto the filter paper which is "count two". The process is repeated until a halo is pronounced around the blue dot. The sample is now returned to the hotplate and brought to a boil, then removed and left to cool for 2 minutes. The solution is then dotted by allowing one drop of the solution to remain on the filter paper, once again, onto the filter paper. If the halo is repeated this indicates that the test is complete. However if the halo does not appear with this dot another 1ml of methylene blue is to be added and the processes continued. No back titration was specified or conducted. Rosenberg (2012) states that the number of dots placed, until the halo is reached, determines the concentration of smectite clays.

D.9 Thin Sections

Thin section samples were collected at the face of each weathering grade as well as from a stockpile after being processed through the primary crushing plant. The samples were cut using a blade saw, into blocks approximately match box size. These were then processed by the University of Canterbury technician where they were glued to a glass sheet with araldite and polished for microscope analysis. The thin sections were analysed using a Leica DM EP microscope between 4x and 20 x magnification in Plane and Polarised Light.

D.10 X-Ray Diffraction

All samples were air dried and then sieved over the 63 µm sieve. 15 g of the sample was placed in a c and mixed with distilled water. This was then added to a 1000ml settling column, ensuring all of the fines were rinsed out of the beaker. Distilled water was added to the column until flush with the 100ml line (Figure D.4). The column was agitated for a minute with a rod finished with a cylindrical plate or sealed and weighted cylinder. When changing between each flask or sample prep all equipment was rinsed with distilled water and samples were always covered with rubber plugs or watch glasses, this was to remove the risk of contamination. The column was left for 8 hours to determine if flocculation occurs (flocculation didn't occur in any of the samples). The sample was then re-agitated ensuring all particles were in suspension and left for another 8 hours. On completion of the time approximately 200ml was poured from the flask, without disturbing the settled fines, into a beaker and dried in the oven at 50°C. This generally took 3 days but varied depending on the amount of water added and beaker used. This material represented the 9phi fraction (2µm) of clay sized particles and was carefully placed into sample vials and to be sent to the University of Canterbury for testing. Testing was completed by Stephen or Catherine Brown. After communication with Stephen Brown the preparation and testing process can be described as follows; samples are prepared by grinding the material using an agate pestle and mortar; ethanol is added to form slurry. This slurry is added to a half a microscope slide to form a thin layer (orientated mount) using a disposable pipette and left to air dry.

The samples are tested using a Philips XRD. Which has the following specifications;

- PW1729 X-ray generator (50kV/40mA)
- PW2273/20 Long fine focus 2.2kW Cu anode x-ray tube
- PW1820/00 Goniometer
- PW1752/00 Monochromator
- PW1711/10 Sealed Gas (Xe) filled proportional detector
- PW 1710 Diffractometer control (connected to PC)

The PC is loaded with Visual XRD controller software and Traces (V4) search-match software using Hanawalt search-match algorithm. The sample is scanned from 3 to 70 degrees two theta with a step size of 0.02 degrees two theta and scan speed of 0.02 degrees two theta per second. When testing for expansive clays the slide is air dried and placed in a desiccator with ethylene glycol and soaked overnight at 60°C. After drying the slide is removed and left to cool to ambient temperature, it is then scanned 3 to 30 degrees two theta. If a slide indicates that there are expansive clays present the same sample slide is placed into a muffle furnace for one hour at 550˚C. Once again it is left to cool and then scanned from 3 to 30 degrees. The result are displayed in graphs which indicate the counts per second.

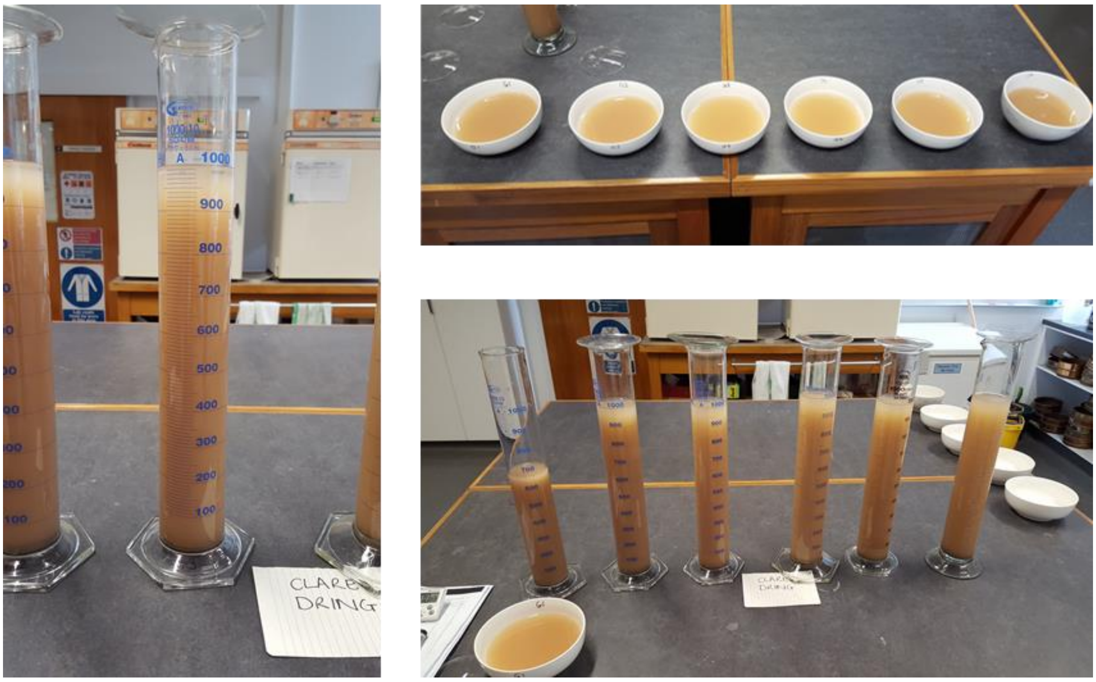

Figure D.4 Settling columns used for extracting 9 phi fraction from the fines passing the 63 sieve µm after 8 hours. Clockwise - Settling columns after agitation. Top Right – top 300ml poured into bowls for evaporation. Bottom Right- First column sample is poured removing only the 9phi fraction

D.11 Scanning Electron Microscope

Cobham Technical Services explain the SEM. It uses a beam of high energy electrons which is focused to a point of the surface of the specimen. It is then scanned in a raster formation. As the electrons reach the surface of the sample they enter the surface layer of atoms and are either in-elastically or elastically scattered. The in-elastically scattered atoms have little energy and are known as secondary electron. Elastically scattered atoms loose little energy and are known as backscatter electrons. The differing energies allow for two detectors to produce separate images from the signals, backscatter electron (BSE) and Secondary electron imagery (SEI).

SEI can travel in curved paths because of their low energy and requires the electrons to be attracted toward the detector. Images can be obtained from holes or around corners and creates a highly topographical image. If an electric charge builds up the electrons can be deflected which creates bright white areas surrounded by darker areas.

BSE travel in straight lines because of their high energies and are usually scattered at high angles. This requires the detector to be placed directly above the sample and create imagery with low topography. These BSE images illustrate the atomic number differences and with brighter areas indicate an area of higher atomic number.

D.12 References

NZS. (1991). NZS 4407: 1991 Methods for sampling and testing road aggregates . New Zealand Standards.

Rosenberg, M. D. (2012). Smectite Clay Content in Rock and Soil Material: A Method for Quantitative Estimation by Methylene Blue Dye Absorption. Institute of Geological and Nuclear Sciences Limited

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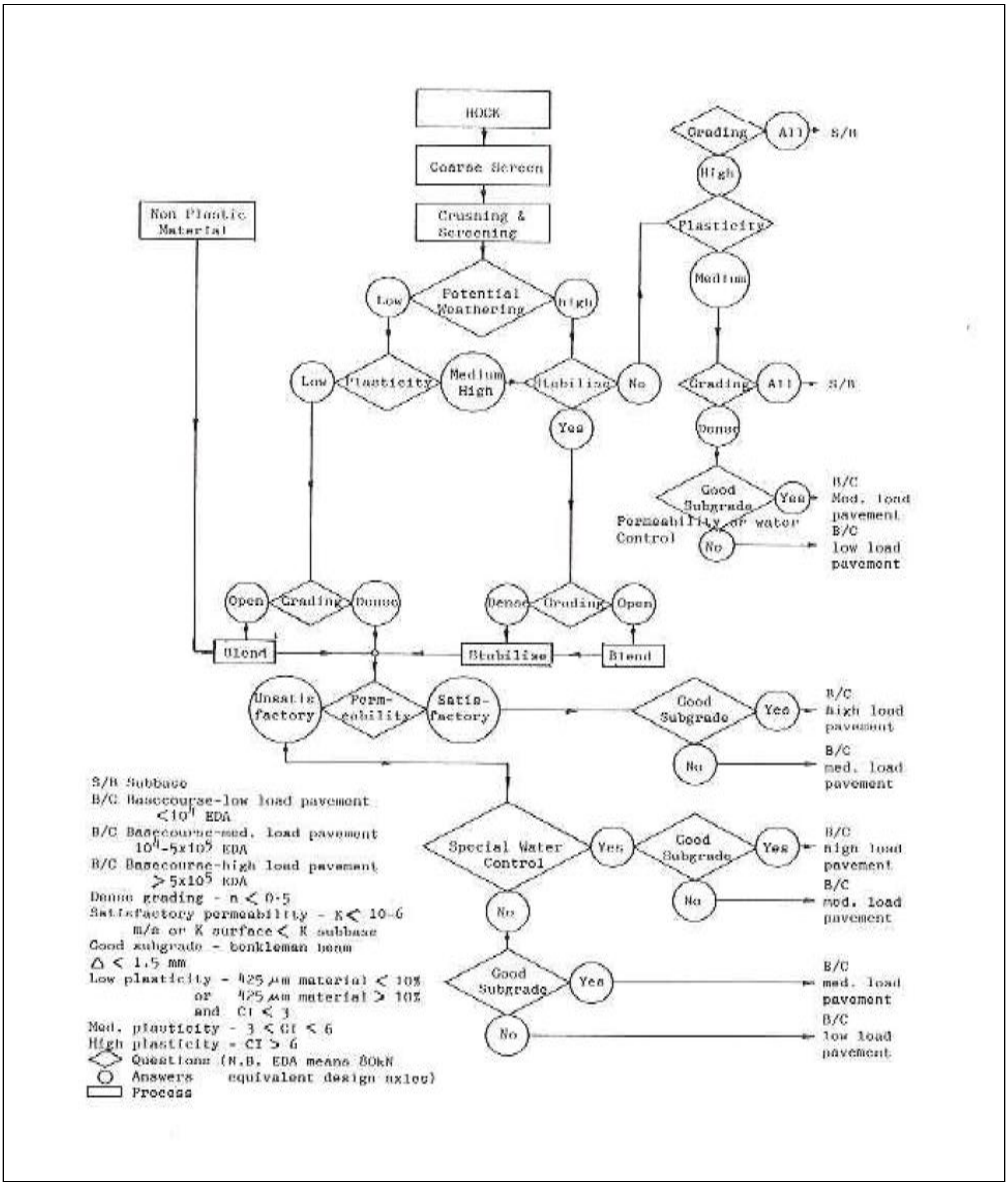
TNZ M/4 N. (2006). *NOTES TO THE SPECIFICATION FOR BASECOURSE AGGREGATE.* Wellington: Transit NeW Zealand.

E. Appendix E: Aggregate Selction Chart



E.1 References

Brennan, G. H. (1987). Selection of Marginal Aggregates for Sealed Road Construction. New Zealand Roading Symposium.

F. Appendix F: Research Plan

F.1 Scope

The scope of this research plan is to detail the tasks which are to be undertaken in a chronological order to complete the research for the MSc thesis. Figure F.1 outlines the tasks in their proposed sequence, these are detailed below. The nature of the project is such that this research plan may change and will be continue to evolve as the project progresses.

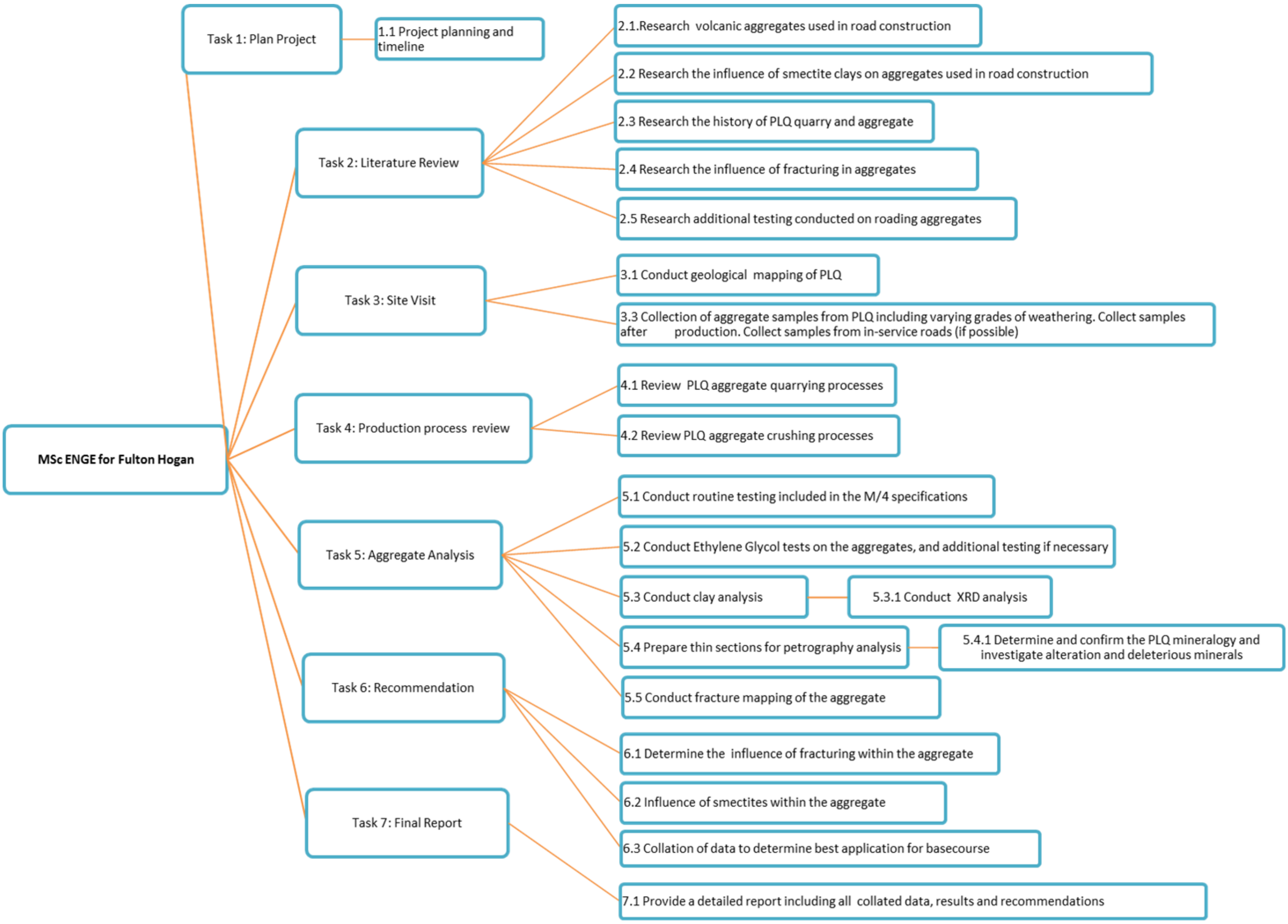


Figure F.1 Research plan flow chart

F.2 Task 3: Site Visit

3.1 Conduct geological mapping of PLQ.

Two days will be spent on mapping the structure, texture and composition of the volcanic layers at freshly quarried sites, as well as older faces.

3.2 Collection of aggregate samples from PLQ including varying grades of weathering (Total amount of required aggregate is summarised in Table1).

- Collect fresh samples before crushing.
- Collect samples after crushing and screening.
- Collect samples from in-service roads (contact other contractors to determine if any maintenance is being conducted and extraction is possible).

A summary of sample categories and testing can be found in the Aggregate Analysis section as well as in Table 1.

- Approximately 100-130 kg of aggregate is required for each round of standard testing; this includes all the TNZ M/4 specifications as well as additional testing.
- Six rounds of each test will be conducted to obtain representative and comparable results.
- Samples that require transportation will be quartered into the specified sample size found in the *Notes to the Specification for Basecourse Aggregate* (TNZ M/4 N, 2006). This is to minimise the logistical complexities of transporting unnecessarily large quantities of material.
- Where possible, aggregate testing will be conducted on site (PLQ Laboratory) by lab staff. This is likely to include all standard tests detailed in the TNZ M/4 specification. Table 1 lists the test to be performed. Where testing cannot be performed on site, aggregate will be transported to the FH Canterbury Lab and testing will be performed there by Clare Dring. 200kg of aggregate will be transported to Canterbury as “backup” material to allow for any further testing, this excludes the quartered and hand samples required for testing listed in Table F.1.

3.3 Collect historic test reports and data

- Collect historic test reports: standard testing and additional testing.
- Document extraction records.
- Detail operational changes and obtain current operations manual.
- Investigate failure sites using information from processed RAMM data.

F.3 Task 4: Production Process Review

4.1 Review PLQ aggregate quarrying processes.

- Review standard practices and operating manuals both historic and current.
- Determine if any discrepancies or contradictions occur.

4.2 Review PLQ aggregate crushing processes

- Review standard practises and operating manuals both historic and current.
- Determine if any discrepancies or contradictions occur.

F.4 Task 5: Aggregate Analysis

Testing will be conducted as follow;

F.4.1 Sampling Categories and Testing

Table F.1 details the amount of aggregate to be required for testing.

Fresh Material

C-Grade Material (6x hand samples)

EG (Ethylene Glycol): Tray method

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

T-Grade Material (6x hand samples)

EG (Ethylene Glycol): Tray method

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

G-Grade Material (6x hand samples)

EG (Ethylene Glycol): Tray method

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

Crushed Material

C-Grade Material (6x samples 100 -130kg)

Particle Size Distribution

Sand equivalent

Clay Index

Plasticity Index

Sand Grading Exponent (Addition to the draft M/4 2012)

Weathering resistance

California Bearing Ratio

Ethylene Glycol Testing: NZTA approved method Including Crushing resistance

EG: Tray

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

T-Grade Material (6x samples 100 -130kg)

Particle Size Distribution

Sand equivalent

Clay Index

Plasticity Index

Sand Grading Exponent (Addition to the draft M/4 2012)

Weathering resistance

California Bearing Ratio

Ethylene Glycol Testing: NZTA approved method Including Crushing resistance

EG: Tray

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

G-Grade Material (6x samples 100 -130kg)

Particle Size Distribution

Sand equivalent

Clay Index

Plasticity Index

Sand Grading Exponent (Addition to the draft M/4 2012)

Weathering resistance

California Bearing Ratio

Ethylene Glycol Testing: NZTA approved method Including Crushing resistance

EG: Tray

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

<u>In-Service Material</u> **(6x samples 100- 130kg each if possible)**

Particle Size Distribution

Sand equivalent

Clay Index

Plasticity Index

Sand Grading Exponent (Addition to the draft M/4 2012)

Weathering resistance

California Bearing Ratio

Ethylene Glycol Testing:

NZTA Including Crushing resistance

EG: Tray

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

<u>Control Stone</u>

Canterbury Greywacke

Particle Size Distribution

Sand equivalent

Clay Index

Plasticity Index

Sand Grading Exponent (Addition to the draft M/4 2012)

Weathering resistance

California Bearing Ratio

Ethylene Glycol Testing: NZTA approved method Including Crushing resistance

EG: Tray

XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)

Petrographic analysis (thin sections)

The control basecourse will be used as a benchmark to compare the results of the PLQ aggregate with. These tests will be conducted at the FH Christchurch lab.

5.1 Conduct routine testing included in the M/4 specifications.

- Collate relevant historic test reports and determine if there are any correlations with this research's test results and if significant changes are noted identify any relation to operational changes.
- Note: fresh samples will not comply with the grading requirements outlined in the TNZ M/4 as they will have bypassed the crushing and screening process, it is expected that this will have an implication on the results therefore standard testing will not be conducted on them.
- Standard testing following draft M/4 specification to be completed on fresh samples, after quarrying/crushing samples and in-service samples.
- Collate data, determine trends and their significance.
- Compare the current and draft M/4 standards and results.

5.2 Conduct Ethylene Glycol tests on the aggregates, and additional testing if necessary

- NZTA accelerated weathering: to determine the durability of the aggregate before and after chemically accelerated testing from each category. Conducted at FH Canterbury by Clare Dring.

  144 kg of sample between 13.2 – 9.5mm (8 kg per test, this includes 6 test for each category and before and after crushing resistance).
- Paige Green (2007) tray method: determine the effect of smectite swelling on the aggregate. 240 pieces of aggregate between 13.2 – 9.5mm.
- XRD ethylene fume test: rapid test to determine if sample contains smectites. 1-5g of ground aggregate is required for each test.

5.3 Conduct clay analysis

5.3.1 Conduct XRD analysis. 1-5g is needed for each test and will be conducted on each category and varying weathering grades. This test will be conducted at the University of Canterbury by XRD technicians.

5.4 Prepare thin sections for petrography analysis

5.4.1 Conduct thin section analysis, sample specimens will be taken from the discarded quarters of section 5.1. These will need to be the size of a hand, fingers not stretched. Where specimens have undergone quarrying/crushing the largest specimen found will be used. The thin sections will be prepared at the University of Canterbury. If possible assign a Smectite Alteration Index number to samples, as used by Houston and Smith (1997).

5.4.2 Determine and confirm the PLQ mineralogy and investigate alteration and deleterious minerals.

5.5 Conduct fracture mapping of the aggregate

Collate information gained from the EG tray test to determine the fracturing response.
Investigate specimens from each category and map any existing fractures.
Investigate thin sections and record facture patterns.
Investigate samples after crushing resistance and map fracturing.
Compare and contrast the fractures between each category before and after crushing tests.
Compare thin section fractures to hand specimen fractures (micro – macro fracturing).

F.5 Expected Results

Fresh Material

When comparing the EG tray results, from the three grades of weathered material, it is expected that material with higher grades of weathering will be susceptible to disintegration and aggregate breakdown than material with less weathering. Un-weathered material is still expected to have some breakdown due to the expected smectite content.

XRD comparisons, of the three grades of weathered material, should indicate higher clay (smectite) contents as the weathering increases.

Thin sections should display higher numbers of deleterious minerals and fracturing as the weathering increases. Fresh fracturing is expected due to the drill and blast quarrying method. There should be an indication between historic (facture infill or colouration) and fresh fractures.

Crushed Material

Comparing the standard test results of the varying weathering grades should indicate an increase in failures or less favourable results as weathering increases.

The crushing resistance will decrease as the weathering increases. Material exposed to the EG will show decreased crushing resistance and an increase in fines. EG tray results can be compared to fresh material results to indicate whether crushing contributes to the breakdown of the material.

XRD and thin sections should be similar to the fresh material results. It is important to compare the thin sections of the fresh material and crushed material as these will exhibit any significant indicators of increased breakdown, fresh fracturing etc. If there are significant indicators then the crushing plant may be a contributing factor and production process may need to be addressed.

In-Service Material

Standard testing results will be compared with the fresh and crushed material results.

This will either confirm weathering grade the aggregate was sourced from, or what type of weathering it represents after being in-service.

EG and crushing test should indicate what limits need to be introduced into the standard testing to confirm the quality of the material and its suitability as a basecourse material.

For material below the decided limit, investigate modifying/stabilising the material, include a cost analysis if possible.

Investigate blending lesser quality material with higher quality material.

Correlate historic test reports with results from test reports conducted in this research. If possible compare in service test reports with corresponding historic report. This is expected to indicate the rate of breakdown. Depending on records correlations may be assigned an approximated time frame, if exact time frame can't be given or found. Where possible assign a weathering category to historic test reports, by matching similar results from this research with results of historic tests.

F.6 Task 6: Recommendations

6.1 Determine the influence of fracturing within the aggregate.

6.2 Influence of smectites within the aggregate.

6.3 Collation of data to determine best application for basecourse.

F.7 Task 7: Final Report

7.1 Provide a detailed report including all collated data, results and recommendations.

Table F.1 Maximum total amount of aggregate required for each test from PLQ. In service material may not be available on request

Test Method	Category	Weathering Grade	Particle Size Range (mm)	Sample Size (kg)	Sieved from (kg)	Minimum number of test	Location of Testing
Particle Size Distribution NZS 4407: 1991, Test 3.8.1	**Quarried/Crushed**	**Un-weathered**	AP40	10	40	6	FH PLQ Lab
		Moderately Weathered	AP40	10	40	6	FH PLQ Lab
		Highly Weathered	AP40	10	40	6	FH PLQ Lab
	In-service aggregate	**As received**	AP40	10	40	6	FH PLQ Lab
Sand equivalent NZS 4407: 1991, Test 3.6 Sand Equivalent Test	**Quarried/Crushed**	**Un-weathered**	passing 4.75	0.5	± 2	6	FH PLQ Lab
		Moderately Weathered	passing 4.75	0.5	± 2	6	FH PLQ Lab
		Highly Weathered	passing 4.75	0.5	± 2	6	FH PLQ Lab
	In-service aggregate	**As received**	passing 4.75	0.5	± 2	6	FH PLQ Lab
Clay Index NZS 4407 : 1991, Test 3.5 *Clay Index Test*	**Quarried/Crushed**	**Un-weathered**	passing 0.075	0.008	0.2	6	FH PLQ Lab
		Moderately Weathered	passing 0.075	0.008	0.2	6	FH PLQ Lab
		Highly Weathered	passing 0.075	0.008	0.2	6	FH PLQ Lab
	In-service aggregate	**As received**	passing 0.075	0.008	0.2	6	FH PLQ Lab
Plasticity Index NZS 4407 : 1991, Test 3.4 *Plasticity Index Test*	**Quarried/Crushed**	**Un-weathered**	passing 0.425	0.25	5	6	FH PLQ Lab
		Moderately Weathered	passing 0.425	0.25	5	6	FH PLQ Lab
		Highly Weathered	passing 0.425	0.25	5	6	FH PLQ Lab
	In-service aggregate	**As received**	passing 0.425	0.25	5	6	FH PLQ Lab

Sand Grading Exponent NZS 4407: 1991, Test 3.8.1	**Quarried/Crushed**	**Un-weathered**	No additional material required, results calculated form Particle Size Distribution test results				
		Moderately Weathered					
		Highly Weathered					
	In-service aggregate	**As received**					
Weathering resistance NZS 4407 : 1991, Test 3.11 *Weathering Quality Index Test*	**Quarried/Crushed**	**Un-weathered**	19.0 - 9.5	2	± 30 or from re-sieved moisture samples	6	FH PLQ Lab
			9.5 - 4.75	3			
		Moderately Weathered	19.0 - 9.5	2	± 30 or from re-sieved moisture samples	6	FH PLQ Lab
			9.5 - 4.75	3			
		Highly Weathered	19.0 - 9.5	2	± 30 or from re-sieved moisture samples	6	FH PLQ Lab
			9.5 - 4.75	3			
	In-service aggregate	**As received**	19.0 - 9.5	2	± 30 or from re-sieved moisture samples	6	FH PLQ Lab
			9.5 - 4.75	3			
California Bearing Ratio NZS 4407 : 1991, Test 3.15 *The California Bearing Ratio Test*	**Quarried/Crushed**	**Un-weathered**	passing 19mm	5.5	20	6	FH PLQ Lab
		Moderately Weathered	passing 19mm	5.5	20	6	FH PLQ Lab
		Highly Weathered	passing 19mm	5.5	20	6	FH PLQ Lab
	In-service aggregate	**As received**	passing 19mm	5.5	20	6	FH PLQ Lab
Ethylene Glycol Testing: NZTA assigned method. Including Crushing resistance NZS 4407 : 1991 Test 3.10	**Fresh Rock**	**Un-weathered**	13.2 – 9.5mm	8	± 50	6	FH Cant Lab
		Moderately Weathered	13.2 – 9.5mm	8	± 50	6	FH Cant Lab
		Highly Weathered	13.2 – 9.5mm	8	± 50	6	FH Cant Lab
	Quarried/Crushed	**Un-weathered**	13.2 – 9.5mm	8	± 50	6	FH Cant Lab
		Moderately Weathered	13.2 – 9.5mm	8	± 50	6	FH Cant Lab
		Highly Weathered	13.2 – 9.5mm	8	± 50	6	FH Cant Lab
	In-service aggregate	**As received**	13.2 – 9.5mm	8	± 50	6	FH Cant Lab
Ethylene Glycol: Tray Method	**Fresh Rock**	**Un-weathered**	13.2 – 9.5mm	40 pieces	taken from EG NZTA discarded	6	FH Cant Lab

					quarter		
		Moderately Weathered	13.2 – 9.5mm	40 pieces	taken from EG NZTA discarded quarter	6	FH Cant Lab
		Highly Weathered	13.2 – 9.5mm	40 pieces	taken from EG NZTA discarded quarter	6	FH Cant Lab
	Quarried/Crushed	**Un-weathered**	13.2 – 9.5mm	40 pieces	taken from EG NZTA discarded quarter	6	FH Cant Lab
		Moderately Weathered	13.2 – 9.5mm	40 pieces	taken from EG NZTA discarded quarter	6	FH Cant Lab
		Highly Weathered	13.2 – 9.5mm	40 pieces	taken from EG NZTA discarded quarter	6	FH Cant Lab
	In-service aggregate	**As received**	13.2 – 9.5mm	40 pieces	taken from EG NZTA quarter	6	FH Cant Lab
XRD Analysis and EG XRD Fume (test conducted on original samples after XRD testing)	**Fresh Rock**	**Un-weathered**	<2µm	min 0.001	Hand sample	6	University of Canterbury
		Moderately Weathered	<2µm	min 0.001	Hand sample	6	University of Canterbury
		Highly Weathered	<2µm	min 0.001	Hand sample	6	University of Canterbury
	Quarried/Crushed	**Un-weathered**	<2µm	min 0.001	Hand sample	6	University of Canterbury
		Moderately Weathered	<2µm	min 0.001	Hand sample	6	University of Canterbury
		Highly Weathered	<2µm	min 0.001	Hand sample	6	University of Canterbury
	In-service aggregate	**As received**	<2µm	min 0.001	Hand sample	6	University of Canterbury
Petrographic analysis (thin sections)	**Fresh Rock**	**Un-weathered**	Hand sized	Hand sized	Hand sample	6	University of Canterbury

ASTM C 295 Standard Practice For Petrographic Examination of Aggregate For Concrete		**Moderately Weathered**	Hand sized	Hand sized	Hand sample	6	University of Canterbury
		Highly Weathered	Hand sized	Hand sized	Hand sample	6	University of Canterbury
	Quarried/Crushed	**Un-weathered**	Hand sized	Hand sized	Hand sample	6	University of Canterbury
		Moderately Weathered	Hand sized	Hand sized	Hand sample	6	University of Canterbury
		Highly Weathered	Hand sized	Hand sized	Hand sample	6	University of Canterbury
	In-service aggregate	**As received**	Hand sized	Hand sized	Hand sample	6	University of Canterbury
MAXIMUM TOTALS				±160	±900		
MAXIMUM TOTAL AGGRGEATE REQUIRED FOR 6 ROUNDS OF TESTING BEFORE QUATERING						**±4500 kg**	

G. Appendix G: Joint Set Data

Table G.1 C-Grade Joint Set Data

C-Grade M4	10/06/2015
Rock Classification	Slightly - moderately weathered, dark bluish grey, massive, PORPYRITIC ANDESITE, very strong, widely spaced jointing, mirco fracture vissible
Mineralolgy	Plagioclase (twinning and elongated), Orthopyroxene
Stike/dip & dip direction of face	29/60 N

CHAINAGE	TYPE	STRIKE	DIP	DIP DIRECTION	PERSISTENCE	APPERATURE/WIDTH	FILL	SURFACE ROUGHNESS	SURFACE SHAPE	WATER FLOW
0.1	Joint	342	82	ENE	0.5	0.3m	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER
0.1	Joint	292	78	N	0.5	0.2m	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER
0.2	Joint	346	88	ENE	0.6	Moderately Wide (2.5-10mm)	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER
0.4	Joint	296	80	N	2	1m	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER
1.4	Joint	26	90	ESE	1.5	0.2m	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER
1.8	Joint	310	40	NE	1	1m	Clay	Rough	Stepped	CONTINUOUS WATER FLOW
2.8	Joint	216	68	SE	1	Open (0.5-2.5mm)	Clay	Rough	Planar	DRY, BUT EVIDENCE OF WATER
3	Joint	188	66	W	4	Open (0.5-2.5mm)	Clay	Rough	Undulating	DRY, BUT EVIDENCE OF WATER
3.6	Joint	300	42	NE	0.5	0.2m	Clay	Smooth	Undulating	SEEPAGE, BUT NO FREE WATER FLOW
3.7	Joint	204	70	W	1.5	Open (0.5-2.5mm)	Clay	Rough	Planar	SEEPAGE, BUT NO FREE WATER FLOW
3.8	Joint	306	38	NE	1.5	0.4m	Clay	Smooth	Stepped	CONTINUOUS WATER FLOW
3.9	Joint	198	74	W	1	Open (0.5-2.5mm)	Clay	Rough	Planar	CONTINUOUS WATER FLOW
4	Joint	310	32	NE	1.5	1m	Clay	Smooth	Planar	CONTINUOUS WATER FLOW
4.8	Joint	226	74	NW	1	Open (0.5-2.5mm)	Clay	Rough	Planar	SEEPAGE, BUT NO FREE WATER FLOW
7.3	Joint	320	34	NE	1.5	1.5m	Clay	Smooth	Stepped	DRY, BUT EVIDENCE OF WATER
7.4	Joint	260	58	N	2	0.3m	Clay	Smooth	Planar	DRY, BUT EVIDENCE OF WATER
7.5	Joint	304	64	NE	0.4	0.3m	Clay	Smooth	Stepped	DRY, BUT EVIDENCE OF WATER
8	Joint	200	66	W	2	0.3m	Clay	Smooth	Stepped	DRY, BUT EVIDENCE OF WATER
9	Joint	316	30	NE	0.5	0.5m	Clay	Smooth	Stepped	CONTINUOUS WATER FLOW
9.2	Joint	204	70	W	0.2	Very Wide (2-10cm)	Clay	Smooth	Stepped	SEEPAGE, BUT NO FREE WATER FLOW
13.9	Joint	316	48	NE	1	0.2m	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER
14	Joint	296	82	NE	0.5	Very Wide (2-10cm)	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER
14.1	Joint	216	68	NW	2	1m	Clay	Rough	Stepped	DAMP BUT NO FREE WATER PRESENT - CONTINUOUS WATER FLOW
15	Joint	328	66	NE	0.5	Open (0.5-2.5mm)	Clay	Rough	Stepped	CONTINUOUS WATER FLOW
15.1	Joint	198	82	E	2	Moderately Wide (2.5-10mm)	Clay	Rough	Stepped	SEEPAGE, BUT NO FREE WATER FLOW
15.2	Joint	200	80	WNW	1.5	Open (0.5-2.5mm)	Clay	Rough	Undulating	DAMP BUT NO FREE WATER PRESENT
15.3	Joint	202	82	WNW	1.5	Partially Open (0.25-0.5mm)	Clay	Rough	Stepped	DAMP BUT NO FREE WATER PRESENT
15.7	Joint	230	80	NW	2	Moderately Wide (2.5-10mm)	Clay	Rough	Stepped	CONTINUOUS WATER FLOW
15.7	Joint	30	50	ESE	4.5	Open (0.5-2.5mm)	Clay	Rough	Stepped	CONTINUOUS WATER FLOW
15.8	Joint	236	84	NW	0.5	0.6m	Clay	Rough	Stepped	DAMP BUT NO FREE WATER PRESENT
16.4	Joint	40	45	SE	1	0.3m	Clay	Rough	Undulating	DAMP BUT NO FREE WATER PRESENT
16.5	Joint	310	60	NE	1	Moderately Wide (2.5-10mm)	Clay	Rough	Undulating	DRY, BUT EVIDENCE OF WATER
16.8	Joint	32	52	SE	2	Partially Open (0.25-0.5mm)	Clay	Rough	Undulating	DRY, BUT EVIDENCE OF WATER
18	Joint	226	56	NW	1	0.3m	Clay	Rough	Stepped	DRY, BUT EVIDENCE OF WATER

Table G.2 T-Grade Joint Set Data

T-Grade M4

9/06/2015

Rock Classification	Slightly - moderately weathered, dark bluish grey, massive, PORPYRITIC ANDESITE, very strong, widely spaced jointing, mirco fracture vissible
Mineralolgy	Plagioclase (twinning and elongated)
Stike/dip & dip direction of face	230/68

CHAINAGE	TYPE	STRIKE	DIP	DIP DIRECTION	PERSISTENCE	TERMINATION	APERTURE/WIDTH	FILL	SURFACE ROUGHNESS	SURFACE SHAPE	WATER FLOW
0	Joint	240	64	WNW	4m	1	Tight (0.1-0.25mm)	CLAY	SMOOTH	Planar	DRY, evidence of water flow
0.4	Joint	166	88	E	4m	1	0.5m	CLAY	ROUGH	Undulating	DRY, evidence of water flow
0.7	Joint	240	70	N	3m	1	Tight - Partially Open (0.1 - 0.5mm)	CLAY	ROUGH	Undulating	DRY, evidence of water flow
0.9	Joint	40	2	SE	0.5m	2	Tight - Partially Open (0.1 - 0.5mm)	CLAY	ROUGH	Undulating	DRY, evidence of water flow
0.9	Joint	90	5	S	0.2m	2	Open (0.5-2.5mm)	CLAY	ROUGH	Stepped	DRY, evidence of water flow
1	Joint	142	70	SW	2	2	Partially Open (0.25-0.5mm)	CLAY	ROUGH	Undulating	DRY, evidence of water flow
1.1	Joint	26	62	NW	2	1	Open (0.5-2.5mm)	CLAY	ROUGH	Undulating	DRY, evidence of water flow
2	Joint	162	72	SW	3	1	Partially Open (0.25-0.5mm)	CLAY	ROUGH	Undulating	DRY, no evidence of water flow
2.9	Joint	210	52	N	1	2	0.2m	CLAY	ROUGH	Stepped	DRY, evidence of water flow
3	Joint	260	76	N	1.5	1	0.3m	CLAY	ROUGH	Undulating	DRY, evidence of water flow
3.1	Joint	166	81	NE	3.5	1	Partially Open (0.25-0.5mm)	CLAY	ROUGH	Undulating	DAMP, no evidence of free flowing water
3.3	Joint	170	76	NE	3	1	Open (0.5-2.5mm)	CLAY	ROUGH	Stepped	DRY, no evidence of water flow
3.4	Joint	236	60	NW	2	2	0.4m	CLAY	ROUGH	Undulating	DRY, no evidence of water flow
3.5	Joint	90	3	S	3.5	1	0.2m	CLAY	ROUGH	Undulating	DRY, evidence of water flow
3.6	Joint	240	62	NW	5	1	1m	CLAY	ROUGH	Stepped	DAMP, no evidence of free flowing water
3.8	Joint	180	84	NE	3.5	1	Open (0.5-2.5mm)	CLAY	ROUGH	Stepped	DRY, no evidence of water flow
4.7	Joint	336	58	NE	2	1	Moderately Wide (2.5-10mm)	CLAY	ROUGH	Undulating	DRY, no evidence of water flow
5	Joint	160	80	W	2	2	0.5m	CLAY	ROUGH	Undulating	DAMP, no evidence of free flowing water
5.3	Joint	240	70	NW	3	1	1m	CLAY	ROUGH	Undulating	DAMP, no evidence of free flowing water
6.4	Joint	236	22	NW	1	2	0.5m	CLAY	ROUGH	Undulating	DAMP, no evidence of free flowing water
8	Joint	220	52	NW	0.5	2	0.5m	CLAY	ROUGH	Stepped	DAMP, no evidence of free flowing water
12	Joint	234	60	NW	2.5	2	0.5m	CLAY	ROUGH	Stepped	WATER FLOW, continuous
13	Joint	214	70	NW	3	1	Partially Open (0.25-0.5mm)	CLAY	ROUGH	Undulating	WATER FLOW, continuous
16.5	Joint	164	82	E	4	1	Open (0.5-2.5mm)	CLAY	ROUGH	Undulating	WATER FLOW, continuous
17	Joint	148	80	SW	4	1	6 to 7	CLAY	ROUGH	Undulating	WATER FLOW, continuous

Table G.3 G-Grade Joint Set Data

G-Grade M4

9/06/2015

Rock Classification	Slightly - moderately weathered, dark bluish grey, massive, PORPYRITIC ANDESITE, very strong, widely spaced jointing, mirco fracture vissible
Mineralolgy	Plagioclase (twinning and elongated)
Stike/dip & dip direction of face	168/70 NE

CHAINAGE	TYPE	STRIKE	DIP	DIP DIRECTION	PERSISTENCE (m)	TERMINATION	APPERATURE/WIDTH	FILL	SURFACE ROUGHNESS	SURFACE SHAPE	WATER FLOW	SPACING
0.6		202	82	WNW	0.5m	Neither end visible	Moderately Wide (2.5-10mm)	Clay	Rough	Stepped	Dry, evidnce of water flow	Moderate, 20-60cm
0.7		104	54	NNE	0.3	One end visible	0.2m	Clay	Rough	Undulating	Dry, evidnce of water flow	Moderate, 20-60cm
1		90	44	N	0.2m	Both ends visible	Partially Open (0.25-0.5mm)	Clay	Rough	Undulating	Damp, no free water flow	Close, 60-200mm
2.1		300	64	NNE	0.2m	Both ends visible	Tight - Partially Open (0.1 -0.5mm)	Clay	Slickenside	Undulating	Dry, evidnce of water flow	Very Close, 20-60mm
2.4		230	90	SW	0.3	Both ends visible	0.1m	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
2.5		304	66	NNE	0.5	One end visible	0.3m	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
2.7		200	80	W	0.2	Neither end visible	0.2m	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
3.5		28	84	ESE	0.3	One end visible	Tight - Partially Open (0.1 -0.5mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
3.6		100	90	S	0.2	One end visible	Tight (0.1-0.25mm)	Clay	Rough	Undulating	Damp, no free water flow	Close, 60-200mm
3.8		200	72	WNW	0.3	One end visible	0.1m	Clay	Rough	Undulating	Damp, no free water flow	Close, 60-200mm
3.9		84	58	S	0.2	One end visible	Open (0.5-2.5mm)	Clay	Rough	Stepped	Dry, evidnce of water flow	Close, 60-200mm
4.1		200	90	WNW	0.2	One end visible	Open (0.5-2.5mm)	Clay	Rough	Stepped	Dry, evidnce of water flow	Very Close, 20-60mm
4.2		108	70	N	0.4	Both ends visible	Open (0.5-2.5mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Very Close, 20-60mm
4.3		188	90		0.5	Neither end visible	Tight - Partially Open (0.1 -0.5mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
4.4		120	60	NE	0.3	Neither end visible	0.2m	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
4.6		192	80	W	0.5	One end visible	Moderately Wide (2.5-10mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
4.8		120	86	NE	0.2	One end visible	Tight - Partially Open (0.1 -0.5mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
5.3		90	84	N	0.1	One end visible	0.3m	Clay	Rough	Stepped	Seepage, drops of water but no free water flow	Very Close, 20-60mm
7.3		188	78	W	0.2	One end visible	0.2m	Clay	Rough	Stepped	Seepage, drops of water but no free water flow	Close, 60-200mm
7.3		124	60	NE	0.3	One end visible	Tight (0.1-0.25mm)	Clay	Rough	Undulating	Seepage, drops of water but no free water flow	Close, 60-200mm
7.4		180	88	W	0.3	Neither end visible	Very Wide (2-10cm)	Clay	Smooth	Undulating	Seepage, drops of water but no free water flow	Close, 60-200mm
7.4		128	65	NE	1M	One end visible	Open (0.5-2.5mm)	Clay	Rough	Undulating	Seepage, drops of water but no free water flow	Close, 60-200mm
7.5		182	90	W	0.2	One end visible	Very Wide (2-10cm)	Clay	Smmoth	Undulating	Seepage, drops of water but no free water flow	Close, 60-200mm
7.5		128	60	NE	1	One end visible	0.2m	Clay	Rough	Undulating	Seepage, drops of water but no free water flow	Close, 60-200mm
9.8		220	70	NW	0.3	Neither end visible	Very Wide (2-10cm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
9.8		118	64	NNE	0.1	Neither end visible	0.2m	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
9.8		200	72	WNW	0.5	Neither end visible	0.3m	Clay	Rough	Stepped	Dry, evidnce of water flow	Close, 60-200mm
9.9		122	66	NE	0.3	Neither end visible	Very Wide (2-10cm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Moderate, 20-60cm
10		190	62	W	0.3	Neither end visible	Moderately Wide (2.5-10mm)	Clay	Rough	Stepped	Dry, evidnce of water flow	Close, 60-200mm
10.1		124	75	SSW	0.2	Neither end visible	Very Wide (2-10cm)	Clay	Rough	Stepped	Dry, evidnce of water flow	Close, 60-200mm
11.4		194	78	W	0.5	Both ends visible	Tight - Partially Open (0.1 -0.5mm)	Clay	Rough	Stepped	Dry, evidnce of water flow	Close, 60-200mm
11.5		130	72	NE	0.2	One end visible	0.4m	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
11.6		201	74	WNW	0.1	Neither end visible	Moderately Wide (2.5-10mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Close, 60-200mm
11.6		114	80	SSW	0.2	Neither end visible	Open (0.5-2.5mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Moderate, 20-60cm
11.7		180	86	E	0.2	One end visible	Partially Open (0.25-0.5mm)	Clay	Rough	Undulating	Dry, evidnce of water flow	Moderate, 20-60cm

H. Appendix H: Historic Test Results

H.1 2003 Test Results

Table H.1 2003 M/4 Test Results

Report Number	Date Tested	Particle Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio (CBR)	Cleaness Value	Percentage Rertained 4.75 mm sieve	Weatehring Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075										
R5646	27/06/2003	100	78	35	19	13	9	6	5	4	3	100	100	100	70						
R5647	27/06/2003	100	76	38	21	13	9	6	5	3	3	100	100	100	64						
R5657	3/06/2003	100	78	47	29	20	14	9	6	4	3	100	100	100	61						
R5658	30/06/2003	100	84	56	35	25	17	11	7	5	3	100	100	100	64						
R5646	27/06/2003	100	78	35	19	13	9	6	5	4	3	100	100	100	70						
PR5663	1/07/2003	100	88	57	35	24	16	10	7	4	3				40						
PR5664	1/07/2003	100	86	55	36	25	17	11	7	4	3				40						
PR5665	1/07/2003	100	89	55	35	25	16	11	7	5	3				40						
R5666	1/07/2003	100	73	39	23	14	10	7	5	4	3	100	100	100	66						
PR5669	3/07/2003	100	81	45	26	17	11	8	6	5	4				40						
R5691	7/07/2003	100	75	43	31	21	13	9	6	4	3				69						
R5708	8/07/2003	100	75	46	34	21	13	9	6	4	3	100	100	100	70						
R5706	8/07/2003	100	73	44	31	20	13	9	6	5	3	100	100	100	65						
R5781	22/07/2003	100	75	39	22	13	8	6	5	4	3	100	100	100	69						
R5780	22/07/2003	100	87	63	45	30	19	14	10	8	6	100	100	100	58						
R5782	22/07/2003	100	86	53	31	19	12	8	6	5	3	100	100	100	73						
R5973	20/08/2003	100	75	49	34	21	14	10	8	6	4	100	100	100	62						
R6057	3/08/2003	100	74	45	31	21	14	9	7	5	4	100	100	100	64						
R6204	8/10/2003	100	84	60	44	31	20	14	10	7	5	100	100	100	64						
R6220	10/10/2003	100	71	42	28	17	11	8	6	5	4	100	100	100	69						
R6243	17/10/2003	100	70	43	30	20	13	9	7	5	4	100	100	100	64						
R6446	26/11/2003	100	66	40	26	16	10	8	6	5	4	100	100	100	62						
R6539	9/12/2003	100	64	41	30	20	13	10	7	5	4	100	100	100	64						
URN 03-8409.1	27/06/2003	100														380					
R5717	11/07/2003																93	95	BA		
R5801	24/07/2003																93	95	BA		
R6317	3/11/2003																91	93	BA		
3661	24/11/2003																				
R6496	4/12/2003																				

H.2 2004 Test Results

Table H.2 2004 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
38013	R6687	100	79	45	31	20	13	10	8	6	5		100	100	100	60						
38019	R6719	100	73	44	33	23	16	11	9	7	5		100	100	100	52						
38026	R6755	100	75	45	33	24	17	12	9	7	6		100	100	100	48						
38026	R6756	100	83	56	40	27	18	13	10	8	6		100	100	100	52						
38040	R6829	100	83	56	38	24	16	12	10	8	6		100	100	100	48						
38042	R6840	100	73	47	30	19	14	12	9	6	4		100	100	100	41						
38047	R6873	100	75	47	33	22	14	11	9	7	6		100	100	100	54						
38056	R6918	100	75	53	44	30	20	14	11	9	7		100	100	100	57						
38070	R6999	100	80	47	30	20	13	9	7	6	4		100	100	100	62						
38078	R7054	100	93	65	44	27	17	12	9	7	6		100	100	100	66						
38079	R7062	100	86	52	35	22	15	10	8	6	5		100	100	100							
38082	R7079	100	83	56	40	25	16	11	9	7	5		100	100	100							
38083	R7082	100	72	36	22	14	9	7	6	5	4		100	100	100	60						
38083	R7102	100	80	44	29	20	14	10	8	6	5					46						
38166	R7428	100	70	38	24	16	11	9	7	5	4		100	100	100	65						
38182	R7481	100	81	42	28	18	12	9	7	6	5		100	100	100	58						
38177	R7506	100	84	54	36	23	15	11	9	7	6		100	100	100	68						
38222	R7617	100	56	23	14	9	7	5	4	3	3		100	100	100	67						
38222	R7618	100	56	23	13	8	6	5	4	3	3		100	100	100	67						
38224	R7652	100	80	48	29	18	11	8	5	4	3					52						
38258	R7740	100	82	54	36	23	14	11	8	7	5					62						
38243	R7765	100	82	45	32	22	15	11	8	6	5		100	100	100	70						
38247	R7828	100	83	45	31	21	14	10	8	6	4		100	100	100	66						
38257	R7829	100	84	46	30	20	14	10	8	6	4		100	100	100	66						
38261	R7852	100	73	50	35	24	15	10	7	5	4		100	100	100	65						
38260	R7851	100	58	41	30	21	15	11	8	6	4		100	100	100	56						
38260	R7841	100	81	48	36	25	17	12	9	7	6		100	100	100	57						
38187	R7835	100	65	44	32	23	16	11	8	6	5		100	100	100	60						
38260	R7834	100	83	48	33	23	16	11	9	7	5		100	100	100	63						
38222	R7862	100	51	33	25	18	19	9	7	5	4		100	100	100	65						

H.3 2005 Test Results

Table H.3 2005 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
URN10859	20/01/2005																6.1					
R8395	21/01/2005	100	75	52	37	26	17	12	9	7	5	100	100	100	59							
R8394	21/01/2005	100	86	56	35	25	18	14	11	8	5	100	100	100	44							
URN10859	18/01/2005																6.1					
R8415	27/01/2005	100	84	64	46	34	23	16	11	8	6	100	100	100	66							
R8437	28/01/2005	100	69	45	32	23	16	11	8	6	4	100	100	100	61							
R8459	2/02/2005	100	82	60	43	32	21	15	11	8	6	100	100	100	68							
R8460	2/02/2005	100	81	56	40	28	19	13	9	7	5	100	100	100	69							
R8463	3/02/2005	100	75	49	34	23	15	11	8	6	5	100	100	100	62							
R8464	3/02/2005	100	66	44	31	22	15	11	8	6	4	100	100	100	57							
R8500	9/02/2005	100	74	53	39	29	19	13	10	7	5	100	100	100	65							
R8499	9/02/2005	100	70	49	36	25	17	12	9	6	5	100	100	100	64							
R8577	22/02/2005	100	75	55	41	29	19	14	10	8	6	100	100	100	63							
R8643	14/03/2005	100	70	47	34	24	18	13	10	7	5	100	100	100	65							
R8674	18/03/2005	100	74	50	38	28	19	14	10	7	5	100	100	100	60							
R8677	22/03/2005																	89	92	BB		
R8678	22/03/2005																	91	93	BA		
R8727	1/04/2005	100	88	68	52	36	23	16	11	8	6	100	100	100	63							
R8731	4/04/2005	100	72	48	35	24	17	12	9	6	5	100	100	100	64							
R8732	4/04/2005	100	65	41	31	22	15	11	8	6	5	100	100	100	59							
R8765	7/04/2005	100	79	58	44	31	20	14	10	8	6	100	100	100	64							
R8766	7/04/2005	100	72	48	36	25	17	13	9	7	5	100	100	100	60							
R8791	8/04/2005	100	78	51	35	23	15	12	10	8	7	100	100	100	63							
R8794	13/04/2005	100	74	45	26	16	11	8	6	5	4	100	100	100	62							
R8795	13/04/2005	100	79	51	32	20	13	9	7	5	4	100	100	100	68							
R8796	13/04/2005	100	85	65	47	32	21	15	11	8	6	100	100	100	57							
R8797	13/04/2005	100	83	54	34	23	15	11	8	5	4	100	100	100	72							
R8798	13/04/2005	100	83	66	50	33	21	14	10	7	5	100	100	100	61							
R8800	15/04/2005	100	69	45	30	20	13	10	7	6	4	100	100	100								
R8812	18/04/2005	100	73	48	34	24	16	12	8	6	4	100	100	100								
R8813	18/04/2005	100	72	48	35	25	18	12	9	6	5	100	100	100								
R8818	20/04/2005	100	76	52	37	27	18	13	9	7	5	100	100	100								
R8819	20/04/2005	100	72	46	33	21	14	10	8	6	5	100	100	100								

R8969	20/05/2005	100	74	50	35	24	16	11	8	6	5	100	100	100	57							
R8989	1/06/2005	100	75	50	35	25	17	13	9	7	5	100	100	100	53							
R9089	28/06/2005	100	74	51	35	23	15	10	7	5	4	100	100	100	64							
R9137	8/07/2005	100	81	52	36	25	16	11	8	6	5	100	100	100	60							
R9136	8/07/2005	100	68	45	29	20	14	10	8	6	4	100	100	100	52							
R9135	8/07/2005	100	65	40	27	20	14	10	7	5	4	100	100	100	49							
R9139	8/07/2005	100	75	48	34	25	18	13	9	7	5	100	100	100	59							
R9143	14/08/2005	100	75	49	34	25	17	11	8	5	4	100	100	100	67							
R9144	14/08/2005	100	73	50	36	26	18	12	9	6	4	100	100	100	68							
R9147	19/08/2005																	91	93	BA		
URN10968	10/02/2005																5.8					
URN11452	24/06/2005																				4	
R9227	10/08/2005																	93	94	BA		
R9248	11/08/2005	100	73	43	27	19	13	9	7	5	4	100	100	100	74							
R9262	11/08/2005	100	77	38	25	17	12	9	7	5	4	100	100	100	55							
R9290	24/08/2005	100	86	45	24	16	11	8	6	4	3											
R9291	25/08/2005	100	70	38	25	17	12	9	7	5	4											
URN11557	5/08/2005	100	70	43	28	19	13	9	7	5	4										0	5.3
URN11560	13/08/2005	100	78	53	33	23	15	10	7	5	4						5.9				9	5.3
R9307	29/08/2005	100	70	44	29	20	13	10	7	5	4	100	100	100	76							
R9336	5/09/2005	100	68	43	28	20	14	10	7	5	4	100	100	100	64							
R9342	7/09/2005	100	83	43	26	17	12	9	7	6	5											
R9337	5/09/2005	100	82	47	30	23	18	14	12	11	9	100	100	100	50							
R9228	10/08/2005	100	78	54	35	23	15	10	7	5	4	100	100	100	62							
R9345	7/09/2005	100	76	49	33	23	14	10	8	6	5	100	100	100	59							
R9343	7/09/2005	100	84	40	24	16	11	8	7	5	4	100	100	100	52							
URN11219	8/04/2005															690, 710, 700						
URN11220	8/04/2005															765, 660, 725						
URN11225	13/04/2005															290						
R9387	12/09/2005	100	78	52	34	23	16	11	8	6	5	100	100	100	71							
URN 11683	12/09/2005																5.9					
URN10968	10/02/2005																					
URN 11397	3/06/2005																				4	4.8
URN 11397	3/06/2005	100	76	50	35	24	16	11	8	6	5											

URN 10859	18/01/2005																6.1					
URN 10951	4/02/2005																3					
URN 10968	10/02/2005																5.8					
URN 11225	13/04/2005																7.4					
URN 11454	28/06/2005																4.8					
URN11454	28/06/2005																8.8					
URN 11683	8/09/2005	100	81	54	38	25	16	11	9	7	5										8	5
R9446	26/09/2005																					
R9538	13/10/2005	100	78	54	37	26	16	11	8	6	5	100	100	100	67							
R9584	19/10/2005	100	60	37	26	19	14	11	8	6	5	100	100	100	58							
R9588	19/10/2005	100	81	52	33	22	15	11	8	6	4	100	100	100	64							
R9610	20/10/2005	100	69	41	27	20	14	10	7	5	4	100	100	100	62							
R9622	25/10/2005	100	66	40	25	18	13	9	7	5	4	100	100	100	62							
R9625	26/10/2005	100	71	45	28	20	13	9	7	5	4	100	100	100	63							
R9648	27/10/2005	100	71	43	28	20	13	9	7	5	4	100	100	100	71							
R9649	27/10/2005	100	71	47	31	21	14	10	7	5	4	100	100	100	69							
R9654	30/11/2005	100	74	49	32	22	15	11	8	6	5	100	100	100	70							
R9660	31/10/2005																	89	91	BB		
R9672	2/11/2005																					
R9693	3/11/2005	100	89	67	48	32	21	15	10	7	6				83							
URN 11888	2/11/2005																6.4					
R9688	3/11/2005																	89	90	CB		
R9884	30/11/2005																	91	94	BA		
R9960	9/12/2005	100	77	54	36	23	15	11	8	5	4	100	100	100	73							
URN 12122	12/12/2005																4.1					
R8532	15/02/2005															310						
R8677	22/03/2005																	89	92	BB		
R8678	22/03/2005																	91	93	BA		
R9147	19/07/2005																	91	93	BA		
URN 10968	10/02/2005																5.8					
URN 11452	24/06/2005	100	72	48	32	22	15	10	8	6	5										4	5
R9227	10/08/2005																	93	94	BA		
URN 11557	5/08/2005	100	70	43	28	19	13	9	7	5	4										0	5.3
URN 11560	13/08/2005	100	78	53	33	23	15	10	7	5	4						5.9				9	5.3
URN 11683	19/09/2005																5.9					
R10184	8/12/2005																	91	92	BA		

H.4 2006 Test Reports

Table H.4 2006 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
R10067	19/01/2006	100	74	52	36	25	16	11	7	5	4	100	100	100	72							
R10112	31/01/2006	100	82	57	36	23	15	11	8	6	4	100	100	100	70							
R10113	27/01/2006	100	74	48	30	18	11	8	5	3	2	100	100	100	67							
R10114	31/01/2006	100	77	51	31	20	13	9	7	5	4	100	100	100	66							
R10115	31/01/2006	100	75	50	32	22	15	11	8	6	4	100	100	100	65							
R10125	1/02/2006	100	74	52	35	19	9	6	5	4	4	100	100	100	63							
R10123	1/02/2006	100	81	56	36	21	12	8	6	5	4	100	100	100	62							
R10184	7/02/2006																	91	92	BA		
R10282	24/02/2006	100	63	42	29	21	15	10	7	5	4	100	100	100	67							
R10283	24/02/2006	100	71	49	34	24	16	11	7	5	4	100	100	100	68							
R10259	21/02/2006	100	74	47	32	22	15	10	8	5	4	100	100	100	63							
R10434	30/03/2006	100	67	46	28	19	13	10	7	6	4	100	100	100	75							
R10716	25/05/2006	100	77	54	38	26	17	12	9	6	5	100	100	100	59							
R10718	25/05/2006	100	70	48	34	21	14	10	7	6	5	100	100	100	57							
R10763	2/06/2006	100	99	68	42	29	20	13	8	4	3											
R10792	8/06/2006	100	76	50	33	21	14	10	7	5	4	100	100	100	60							
R10872	26/06/2006	100	61	34	23	16	11	8	6	4	3	100	100	100	54							
R10886	29/06/2006	100	79	46	32	22	15	11	8	6	4	100	100	100	60							
URN 12922	11/07/2006																4.3					
R10913	11/07/2006	100	70	42	30	21	15	11	8	6	4	100	100	100	61							
R10915	10/08/2006																					
R10912	11/07/2006	100	77	56	39	28	19	14	10	8	6	100	100	100	39							
R10908	6/07/2006	100	81	48	33	23	16	11	8	6	4	100	100	100	63							
R10978	27/07/2006	100	63	33	21	15	11	8	6	5	4	100	100	100	59							
R10982	2/08/2006	100	75	49	34	24	16	11	8	6	5	100	100	100	64							
R11041	16/08/2006																	93	93	BA		
URN13010	23/08/2006															260, 235	4.7					
R11224	28/09/2006	100	66	42	30	20	13	10	7	6	4											
R11231	28/09/2006	100	79	50	35	24	16	11	8	6	5											
R11216	27/09/2006	100	87	59	43	29	19	14	10	7	5	100	100	100	71							
R11217	27/09/2006	100	58	37	26	19	13	9	7	5	4	100	100	100	71							
R11295	9/10/2006	100	70	46	32	21	13	10	8	6	5	100	100	100	55							

R11396	20/10/2006	100	67	48	36	25	17	11	8	6	4	100	100	100	67							
R11433	2/11/2006	100	71	54	40	28	18	13	10	7	5	100	100	100	63							
R11453	6/11/2006	100	69	49	37	26	17	13	9	7	5	100	100	100	52							
URN13269	24/10/2006																6.7					
URN13296	24/10/2006																					5.3
URN13269	24/10/2006																				0	
R11483	13/11/2006	100	75	54	40	27	17	12	9	7	5	100	100	100	64							
R11506	20/11/2006	100	75	55	38	26	17	12	8	6	5	100	100	100	62							
URN13339	17/11/2006																6.3				0	5.5
R11557	30/11/2006	100	56	37	23	16	11	8	6	4	3	100	100	100	69							
R11573	4/12/2006	100	70	52	35	22	13	9	7	5	4	100	100	100	62							
R11584	5/12/2006	100	65	49	35	24	17	12	9	6	5				64							
R11608	7/12/2006	100	70	54	38	28	19	14	10	7	6	100	100	100	60							
R11620	8/12/2006																	82	91	BB		
R11587	6/12/2006	100	72	58	45	32	22	16	12	8	6	100	100	100	63							
R11699	19/12/2006	100	65	49	36	26	17	13	9	7	5	100	100	100	55							
R11716	20/12/2006	100	76	57	38	25	17	12	9	7	5											
R11727	21/12/2006	100	74	51	34	23	15	10	8	6	5	100	100	100	60							
URN13503	19/12/2006															230	6.8				0	5.5
R12882	7/08/2006																	78	92	BB		
R10960	26/04/2006																	91	95	BA		
R10652	12/05/2006																	85	95	BB		

H.5 2007 Test Reports

Table H.5 2007 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
R11735	10/06/2007	100	59	43	31	21	14	10	8	6	5	100	100	100	55							
R11757	12/06/2007	100	68	51	37	26	18	13	9	7	5	100	100	100	57							
R11788	17/01/2007	100	63	48	38	27	19	14	11	9	7	100	100	100	53							
R11812	19/01/2007	100	75	58	44	30	20	14	11	8	6	100	100	100	62							
R11912	8/12/2007	100	74	60	45	34	23	16	11	7	5	100	100	100	60							
R11924	12/02/2007	100	64	49	35	25	17	12	9	6	5	100	100	100	63							
R11934	14/02/2007	100	81	64	45	32	21	15	11	7	6	100	100	100	68							
R11951	16/02/2007	100	82	64	45	32	21	14	10	7	5	100	100	100	63							
R11960	19/02/2007	100	74	59	41	29	19	13	8	5	4	100	100	100	69							
L/155/07	19/02/2007																5.8					
R11961	20/02/2007	100	78	59	44	34	24	17	11	8	6	100	100	100	57							
L/149/07	20/02/2007																					
I/149/07	20/02/2007																4					
R12882	22/02/2007																					
URN 15217	14/01/2008																5.2			BB	15	6.4
R13697	21/12/2007																	89	94	BB		
URN 15105	4/12/2007	100	72	49	35	24	17	12	10	7	6											
URN 15106	4/12/2007															315	6.1					
URN 14919	14/11/2007																6.6				0	
R13233	12/10/2007																	89	92	BB		
URN 14800	10/10/2007																6.4				0	5.1
URN 14716	17/09/2007	100	80	55	39	27	18	13	9	7	5											
URN 14724	20/09/2007	100	78	54	38	26	18	13	10	7	6											
URN 14723	20/09/2007	100	78	52	37	25	16	12	9	7	5											
URN 14392	11/07/2007	100	76	52	38	25	17	12	9	7	6											
URN 14036	8/05/2007	100	80	53	37	25	17	12	9	7	5					250	7.3				0	5.3
R11503	17/11/2007																	83	83	CB		
R12148	27/11/2007																	89		BB		
URN 13722	19/02/2007	100	70	62	44	30	21	14	10	7	5						4				0	5
URN 13275	20/02/2007																5.8					
R13360	8/10/2007																	85	93	BB		
R13147	15/08/2007																	91	93	BA		
R13149	21/09/2007																	78	95	BB		
R12874	11/06/2007																	91	92	BA		
R12584	18/06/2007																	85	92	BB		
R12362	11/05/2007																	91	93	BA		

H.6 2008 Test Reports

Table H.6 2008 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
11/01/2008	R13731	100	78	54	39	26	17	13	10	8	6	100	100	100	68							
23/01/2008	R13791	100	75	49	33	20	12	9	7	5	4	100	100	100	64							
10/01/2008	URN 15217	100	76	55	39	25	17	12	9	7	6					280						
29/01/2008	R13822																87	93	BB			
12/02/2008	R13889	100	67	46	33	23	15	11	8	6	5	100	100	100	66							
14/02/2008	R13905	100	74	50	36	25	16	12	9	7	5	100	100	100	56							
19/02/2008	URN 15368																			0	4.5	
31/01/2008	URN 15289																			0		
14/01/2008	URN 15217																			15	6.4	
29/02/2008	R13975	100	73	46	32	22	15	11	8	6	5	100	100	100	52							
29/02/2008	R13980																89	92	BB			
13/03/2008	R14051	100	73	47	32	21	14	10	8	6	5	100	100	100	56							
17/03/2008	R14060																83	93	BB			
20/03/2008	R14087	100	74	45	29	18	12	9	7	5	4	100	100	100	61							
25/03/2008	R14095	100	75	48	33	23	16	11	8	6	4	100	100	100	64							
13/03/2008	URN 15470																			0	4	
4/04/2008	R14155	100	78	50	33	21	13	10	7	6	4	100	100	100	65							
4/04/2008	R14156	100	74	47	32	23	16	12	9	6	5	100	100	100	61							
9/04/2008	R14171	100	76	53	37	26	17	12	9	6	5	100	100	100	64							
10/04/2008	URN 15560																			0	4.3	
18/08/2008	R14213																87	94	BB			
10/04/2008	URN 15560	100	81	57	41	29	20	13	10	7	5											
9/05/2008	R14270																83	92	BB			
15/05/2008	R14295	100	68	47	34	24	17	12	9	7	5	100	100	100	54							
13/05/2008	R14272	100	72	49	35	21	13	10	8	6	5	100	100	100	51							
9/05/2008	URN 15651	100	76	43	36	24	17	12	9	7	6					280						
11/06/2008	R14422	100	78	57	42	31	20	14	10	7	5	100	100	100	53							
14/05/2008	R14275	100	76	49	34	22	15	11	8	6	5	100	100	100	60							
13/06/2008	URN 15760																			8	3.3	
18/06/2008	R14424	100	76	51	35	25	17	12	9	6	5	100	100	100	65							
23/06/2008	R14452																89	92	BB			
3/07/2008	R14496	100	74	46	32	21	14	10	8	6	5	100	100	100	59							
16/07/2008	R14580																78	92	BB			

14/08/2008	R14640																71	89	CB			
14/08/2008	R14647	100	74	49	36	25	16	12	9	7	5	100	100	100	45							
15/08/2008	URN 15965																			0	7.1	
14/08/2008	URN 15965	100	76	52	38	27	19	14	10	8	6											
18/07/2008	URN 15894	100	74	50	37	25	17	13	10	8	6					325						
10/09/2008	R14728	100	54	33	23	16	12	9	7	6	5	100	100	100	43							
12/09/2008	R14748	100	77	55	38	24	16	11	8	6	5				57							
15/09/2008	URN 16035																		44	17	5.2	
15/08/2008	URN 15965																			0	7.1	
12/09/2008	R14755																87	89	CB			
9/10/2008	S-0342	100	79	60	44	32	23	17	10	8	6	100	100	100	52							
8/10/2008	S-0340	100	80	60	45	32	21	14	10	7	6	100	100	100	50							
16/10/2008	R14759																87	93	BB			
8/10/2008	S-0340																				7.1	
17/10/2008	S-0448	100	69	49	35	24	16	12	9	7	6	100	100	100	47							
22/10/2008	S-0213																			5		
3/11/2008	S-0590	100	74	54	39	28	18	13	9	7	5	100	100	100	65							
8/10/2008	S-0340																71	88	CB			
10/11/2008	S-0661	100	67	44	32	22	15	11	9	7	5	100	100	100	59							
7/11/2008	S-0661	100	66	44	37	31	22	15	11	9	7					240	72	91	BB	0	6.7	
25/11/2008	S-0911	100	74	52	37	25	17	12	9	7	6	100	100	100	61							
3/12/2008	S-1033	100	68	48	36	24	16	12	9	7	5	100	100	100	57		87	91	BB	5	4.7	
15/12/2008	S-1201	100	73	51	37	23	13	9	6	5	4	100	100	100	60							

H.7 2009 Test Reports

Table H.7 2009 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
S-0000	7/01/2009	100	72	49	35	21	14	10	7	6	5	100	100	100	66	310	83	88	CB	6		
S-0120	27/01/2009	100	78	56	40	27	18	13	9	7	5	100	100	100	66							
S-0135	29/01/2009	100	68	47	33	22	14	10	7	6	5	100	100	100	66							
S-0241	11/02/2009	100	67	44	31	21	14	10	8	6	5	100	100	100	64							
S-0256	11/02/2009	100	63	42	30	21	14	10	7	6	4	100	100	100	62					0	4.1	
S-0396	19/02/2009	100	69	51	39	27	18	13	10	7	6	100	100	100	58							
S-0257	10/02/2009															250						
S-0491	5/03/2009	100	73	55	40	28	19	14	11	8	6	100	100	100	67	410	77	91	BB	0	3.4	
S-0485	13/03/2009																					
S-0613	17/03/2009	100	60	40	29	20	14	10	8	6	5	100	100	100	58							
S-0486	11/03/2009																					
S-0487	18/03/2009																					
W0189	3/03/2009																					
S-0659	19/03/2009	100	77	60	46	31	20	14	11	8	7	100	100	100	61							
S-0986	7/04/2009	100	70	50	36	25	17	13	10	7	6	100	100	100	57		85	92	BB			
S-1101	15/04/2009	100	66	50	38	27	18	13	10	7	6	100	100	100	53							
S-1341	5/05/2009																					
S-1574	18/05/2009	100	63	45	32	20	13	9	7	6	4	100	100	100	69		91	95	BA	0	4.5	
S-1902	8/06/2009	100	72	44	29	19	13	9	7	6	5	100	100	100	61							
W0451	7/05/2009	100	72	49	34	21	13	10	7	6	4					235				0	4.5	
S-1981	11/06/2009	100	76	49	32	21	13	9	7	6	5	100	100	100	56							
S-1985	16/06/2009	100	68	42	26	17	11	9	7	6	5	100	100	100	59		93	94	BA	0	6	
S-2046	24/06/2009	100	74	51	36	25	17	12	9	7	6	100	100	100	50							
S-2036	23/06/2009	100	68	41	27	17	11	8	7	5	4	100	100	100	52							
S-1985	16/06/2009	100	70	40	25	16	11	8	7	6	5											
S-1574	11/05/2009																91	95	BA			
S-2093	1/07/2009	100	68	44	28	18	11	7	5	4	3											
S-2230	17/07/2009	100	77	57	42	30	20	15	11	9	7	100	100	100	58							
S-2244	22/07/2009	100	69	47	33	22	15	11	9	7	6	100	100	100	50							
S-2230	17/07/2009	100	75	55	40	27	18	13	11	8	7					280				0	4.8	
S-2500	11/08/2009	100	65	44	31	21	14	11	8	7	5	100	100	100	49		87	95	BB	0	5.6	
S-2230	17/07/2009																87	92	BB			

S-2648	2/09/2009	100	73	50	36	26	18	13	10	7	6	100	100	100	48							
S-2665	8/09/2009															310	89	93	BB	0	5.2	
S-2854	2/10/2009	100	69	53	41	27	18	12	9	7	6	100	100	100	57							
S-03059	11/11/2009	100	64	44	31	21	15	11	9	7	6	100	100	100	56							
S-03075	17/11/2009	100	75	53	37	25	16	11	9	7	6	100	100	100	61							
S-3059	11/11/2009															340				0	4.6	
S-03142	25/11/2009	100	68	49	35	23	15	11	9	7	6	100	100	100	61							
S-03166	30/11/2009	100	70	52	39	28	19	14	11	9	7	100	100	100	55							
S-03059	11/11/2009																91	95	BA			
S-03255	9/12/2009	100	72	55	41	29	20	14	11	9	7	100	100	100	64							
S-03166	30/11/2009																91	94	BA	0	4.2	

H.8 2010 Test Reports

Table H.8 2010 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
S-00047	18/01/2010	99	65	45	33	22	15	11	9	7	6	100	100	100	55		91	95	BA	16	4.7	
S-00140	28/01/2010	100	68	49	37	24	16	11	9	7	5	100	100	100	63	395						
S-00217	9/02/2010	100	69	50	37	24	16	12	9	7	6	100	100	100	59					0	3.5	
S-00217	9/02/2010	100	72	51	38	25	18	13	10	8	6						93	95	BA			
S-00342	5/03/2010	100	73	53	38	25	17	12	10	8	6	100	100	100	64							
S-00417	12/03/2010	100	71	49	34	21	13	9	7	6	5	100	100	100	63							
S-00331	3/03/2010	100	63	44	33	24	16	12	9	7	6	100	100	100	59	315	91	95	BA	14	4	
S-00342	8/03/2010	100	73	53	38	25	17	12	10	8	6	100	100	100	64							
S-00630	19/04/2010																91	95	BA	0	3.1	
S-00746	30/04/2010	100	64	46	34	24	16	12	10	8	6	100	100	100	58							
S-00766	4/05/2010	100	74	48	32	21	13	10	8	6	5	100	100	100	58							
S-00856	20/05/2010	100	71	50	36	24	15	11	9	7	6	100	100	100	53							
S-00986	14/06/2010	99	56	35	26	18	13	10	8	7	5	100	100	100	60							
S-00993	16/06/2010	100	69	48	35	24	17	12	10	8	6	100	100	100	58		89	93	BB	0	4	
S-01019	24/06/2010	100	63	41	29	20	14	10	8	7	5	100	100	100	49							
S-01030	28/06/2010	100	73	50	34	23	16	12	9	8	6	100	100	100	53							
S-01099	14/07/2010	100	73	51	34	24	15	11	7	4	3											
S-01117	16/07/2010	100	73	55	39	28	19	14	11	9	7	100	100	100	48							
S-01100	15/07/2010	100	59	40	29	20	14	11	8	7	6	100	100	100	48							
S-01110	15/07/2010	100	75	47	31	21	13	9	6	4	2				37							
S-01162	27/07/2010	100	76	56	39	24	15	12	9	8	7	100	100	100	62	245				15	4.6	
S-01223	9/08/2010	100	74	52	36	22	15	11	9	8	6	100	100	100	57					0	4.5	
S-01285	24/08/2010	100	80	56	39	27	19	14	10	8	6	100	100	100	60							
S-01335	1/09/2010																					
S-01162	27/07/2010																87	93	BB			
S-01223	6/08/2010																89	93	BB			
S-01724	9/11/2010	100	75	55	38	27	18	13	10	7	5	100	100	100	57							
S-01653	5/11/2010	100	76	57	41	26	16	12	9	7	6	100	100	100	58							
S-01653	26/11/2010																			11	4.1	
S-01960	3/12/2010	100	64	47	34	24	17	13	10	7	5	100	100	100	62	260	85	93	BB	8	4.2	
S-01653	9/12/2010																87	92	BB			
S-02104	15/12/2010	100	71	53	39	28	19	14	11	8	6	100	100	100	56							
S-02164	16/12/2010	100	79	55	39	28	19	14	10	8	6	100	100	100	42							
S-02104	21/12/2010																93	94	BB	10	3.5	
S-01563	7/10/2010																89	94	BB			

H.9 2011 Test Reports

Table H.9 2011 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
2/02/2011	S-00216	100	68	44	30	21	15	11	9	7	5	100	100	100	52	155						
11/02/2011	S-00135	100	62	43	30	20	14	10	8	7	6	100	100	100	45							
22/02/2011	S-00480	100	63	45	32	24	16	12	9	7	5	100	100	100	43							
21/02/2011	S-00477	100	60	39	26	17	12	10	8	6	5	100	100	100	44							
9/02/2011	S-00332															145	85	92	BB	0	5.7	
21/02/2011	S-00573	100	71	52	39	27	18	13	10	7	6	100	100	100	56							
3/03/2011	S-00635	100	66	44	31	21	14	11	8	6	5	100	100	100	53							
3/03/2011	S-00642	100	66	45	32	22	15	11	9	7	5	100	100	100	48							
4/03/2011	S-00635	100	66	43	30	21	15	11	8	7	5									5	4.5	
25/03/2011	S-00974	100	69	50	37	26	18	13	10	8	6	100	100	100	60							
22/03/2011	S-00963	100	74	56	43	30	20	14	11	8	6	100	100	100	59							
20/04/2011	S-01183	100	73	50	35	25	17	13	10	8	6	100	100	100	60							
29/04/2011	S-00635																87	92	BB			
5/05/2011	S-01396																85	92	BB			
12/05/2011	S-01436	100	79	62	48	35	24	17	13	10	7	100	100	100	59	265	85	92	BB	0	4.2	
3/05/2011	S-01396	100	67	50	36	26	17	13	10	7	6	100	100	100	63					0	4	
1/06/2011	S-01560	100	70	49	33	22	15	11	9	7	5	100	100	100	53							
9/06/2011	S-01568	100	66	47	35	24	16	12	9	7	6	100	100	100	48		85	93	BB		4.8	
21/06/2011	S-01647	100	73	52	38	26	18	13	10	8	6	100	100	100	56							
24/06/2011	S-01648	100	77	54	39	28	19	14	11	8	6	100	100	100	41							
2/06/2011	S-01568	100	66	47	35	24	16	12	9	7	6	100	100	100	48		85		BB	11	4.8	
26/07/2011	S-01798	100	73	51	36	25	18	13	11	8	7	100	100	100	52	170	82	92	BB	0	4	
4/08/2011	S-01843	100	75	56	41	28	18	13	10	8	7	100	100	100	52							
17/08/2011	S-01901	100	66	46	35	25	18	13	10	7	6	100	100	100	44		91	95	BA	12	4.1	
14/09/2011	S-02104	100	68	49	36	24	17	13	10	8	7	100	100	100	53		83	94	BB	10	4	
23/09/2011	S-02142	100	64	38	26	18	12	9	7	6	5	100	100	100	45							
7/10/2011	S-02370	100	75	55	40	26	18	13	10	8	6	100	100	100	52							
20/10/2011	S-02510	100	71	48	34	23	16	12	9	7	6	100	100	100	40		89	94	BB			
9/11/2011	S-02816	100	77	56	42	28	18	13	10	8	7	100	100	100	40							
9/11/2011	S-02835	100	67	47	34	23	15	11	8	7	6	100	100	100	39	190				16	5.2	
29/11/2011	S-02967	100	82	53	45	31	21	15	11	9	7	100	100	100	37							
29/11/2011	S-02968	100	72	54	41	29	20	14	11	8	7	100	100	100	37							
30/11/2011	S-02969	100	74	53	39	26	18	13	10	8	7	100	100	100	30							
2/12/2011	S-03046	100	70	51	37	26	18	13	10	8	7	100	100	100	34							
8/12/2011	S-03210	100	80	57	41	30	20	14	10	8	6				54							
6/12/2011	S-03153	100	65	47	34	23	16	12	9	7	6	100	100	100	33							
15/12/2011	S-03300	99	70	48	34	23	15	11	8	6	5	100	100	100	58		89	4	BB	9	3.6	
10/11/2011	S-02835																87	92	BB			
24/03/2011	S-00982																93	94	BA			

H.10 2012 Test Reports

Table H.10 2012 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
S-00316	27/01/2012	100	70	47	33	22	15	11	8	6	5	100	100	100	59	260	6.2	93	95	BA	0	4.4
S-00377	27/01/2012	100	73	50	36	24	16	12	9	7	5	100	100	100	60							
S-00378	27/01/2012	100	71	49	34	22	15	11	8	6	5	100	100	100	64							
S-01044	5/03/2012	100	81	59	42	28	19	14	11	9	7				51							
S-00869	23/02/2012	100	68	50	36	24	16	11	9	7	5	100	100	100	50		5.3	91	94	BA	0	4.5
S-01389	19/03/2012	100	72	50	35	26	19	14	11	8	6	100	100	100	46							
S-01376	19/03/2012	100	77	56	40	28	19	14	11	8	7	100	100	100	56	235	5.4	95	95	BA	0	5.6
S-02559	8/05/2012	100	67	43	30	21	14	10	8	6	5	100	100	100	48							
S-02098	20/04/2012	100	80	56	40	29	20	15	12	9	7	100	100	100	55		4.7	89	94	BB	11	5.1
S-02704	14/05/2012	100	83	57	41	27	18	14	11	9	7	100	100	100	52							
S-02855	21/05/2012	99	74	53	38	25	17	13	10	8	6	100	100	100	51		4	80	91	BB	6	10.8
S-03184	6/06/2012	100	80	56	40	29	21	15	11	8	6	100	100	100	54							
S-03385	15/06/2012	100	78	59	43	29	19	14	10	8	7	100	100	100	59	295	5.3	80	92	BB	6	7
S-03883	23/07/2012	100	64	48	36	27	19	14	10	8	6	100	100	100	41	260	3.3	87	93	BB	10	5.3
S-03951	27/07/2012	98	74	51	37	26	18	13	9	7	5	100	100	100	49							
S-04214	10/08/2012	99	72	53	41	29	19	13	9	7	6	100	100	100	52		5.7	93	94	BA	12	5.3
S-04618	14/09/2012	100	74	56	41	30	20	14	11	8	6	100	100	100	51	155	5.5	83	93	BB	10	5.9
S-05094	10/10/2012	100	69	49	34	23	16	12	9	7	5	100	100	100	56							
S-05290	26/10/2012	100	70	52	38	27	18	14	10	8	6	100	100	100	52							
S-05134	11/10/2012	100	64	44	33	24	17	12	9	7	5	100	100	100	60		5.3	89	95	BB	8	3.8
S-05612	8/11/2012	100	77	59	44	31	20	13	9	6	6	100	100	100	57	240	5.1	72	92	BB	0	4.8
S-06024	29/11/2012	100	69	50	36	23	14	8	7	5	5	100	100	100	56							
S-06179	7/12/2012	100	76	54	39	26	17	12	9	7	5	100	100	100	59	165	5	93	96	AA	5	4.5
S-06392	12/12/2012	100	71	51	37	28	19	14	10	7	5	100	100	100	64							

H.11 2013 Test Reports

Table H.11 2013 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
S-00037	11/01/2013	100	75	57	42	32	24	18	13	9	6	100	100	100	64	300	5.7	83	94	BB	5	4.3
S-00497	14/02/2013	99	68	49	36	25	17	12	9	6	5	100	100	100	55							
S-00503	18/02/2013	100	81	62	45	30	20	14	10	7	6	100	100	100	63			82	93	BB	3	4.5
S-00816	6/03/2013	100	78	56	39	26	17	12	9	7	5											
S-00931	13/03/2013	100	74	54	36	28	18	13	10	7	5	100	100	100	58	205	6.1	77	93	BB	11	6.1
S-01237	4/04/2013	100	73	52	38	25	16	12	9	7	5	100	100	100	58		3.7	60	91	BC	5	4.7
S-02219	5/06/2015	100	65	44	31	23	16	12	9	7	5				51		4.4	83	94	BB	6	4.6
S-02751	4/07/2013	100	61	39	28	20	14	10	8	6	5	100	100	100	46	225	4.4	83	91	BB	10	4.6
S-04072	4/09/2013	100	56	34	23	16	11	8	6	5	4	100	100	100	56	245	5.7	69	90	CC	9	6.1
S-04732	26/09/2013	98	64	43	30	21	14	10	8	6	5				49							
S-04732	26/09/2013	98	64	43	30	21	14	10	8	6	5	100	100	100	49							
S-04885	15/10/2013	98	66	46	32	21	14	10	8	6	5	100	100	100	53		5.5	77	90	CB	2	3.3
S-05458	6/11/2013	99	54	32	22	15	11	8	6	5	3	100	100	100	46	190	5.8	85	90	CB	4	4.7
S-01708	14/05/2013	100	69	48	34	23	16	11	9	7	5	100	100	100	58	215	4	91	93	BA	6	5.7
S-03022	15/07/2013															165	3.6	77		CB	6	
S-00927	11/03/2013																5.2					

H.12 2014 Test Reports

Table H.12 2014 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
BOP14S-00379	5/02/2014	100	82	53	36	24	17	12	9	7	6				47	200	8.7	75	89	CB	6	6.6
BOP14S-00447	10/02/2015	100	81	53	35	24	16	12	10	8	6				39							
BOP14S-00506	14/02/2014	100	79	48	31	22	15	11	8	7	5				42							
BOP14S-01206	19/03/2014	100	64	39	26	17	12	9	7	5	4	100	100	100	54							
BOP14S-01460	31/03/2014	100	69	48	33	22	15	11	8	7	5				54							
BOP14S-01461	31/03/2014	100	69	46	32	23	15	11	8	6	5				56							
BOP14S-01524	3/04/2014	100	70	48	33	22	15	11	8	6	5	100	100	100	59	270	5.3	85	94	BB	8	5.8
BOP14S-01653	14/04/2014	100	77	55	38	27	17	11	8	6	5											
BOP14S-02082	12/05/2014	100	60	40	27	17	11	8	6	4	3											
BOP14S-01973	5/05/2014	100	69	49	31	23	16	11	8	6	5	100	100	100	45	130	7.4	77	89	CB	6	5.3
BOP14S-02998	30/07/2015	100	81	58	39	26	16	11	8	6	5											
BOP14S-03163	11/08/2014	100	70	48	33	23	15	11	8	6	5											
BOP14S-02887	21/07/2014	100	80	53	35	23	15	10	7	5	4				72			91	94	BA	7	5
BOP14S-03210	14/08/2014	100	69	44	30	22	15	11	8	6	5	100	100	100	61	175	4.4	87	93	BB	9	4.1
BOP14S-03747	17/09/2014	100	76	54	37	26	18	13	9	7	5	100	100	100	50	220	5.6	85	93	BB	12	6.4
BOP14S-03939	1/10/2014	100	72	48	33	22	15	12	9	7	6	100	100	100	39		4.7	89	93	BB	8	4.7
BOP14S-04550	17/11/2014	100	75	54	37	26	18	13	10	7	5											
BOP14S-04504	12/11/2014	100	83	55	36	25	17	12	9	6	5	100	100	100	64							
BOP14S-04510	12/11/2014	100	81	58	40	27	18	12	9	7	5											
BOP14S-04652	25/11/2014	100	76	54	36	24	16	10	8	6	5					235	5.5	89	93	BB	6	4.5
S-00137	17/01/2014																4.6					
S-01019	12/03/2014	100	66	47	32	21	13	9	7	5	4	100	100	100	65	305	4.7	89	93	BB	9	5.2
S-02651	3/07/2014	100	62	39	26	18	13	10	7	6	4	100	100	100	43	225	5.9	87	94	BB	10	5.7
BOP14S-01019	13/03/2014																	89	93	BB		

H.13 2015 Test Report

Table H.13 2015 M/4 Test Results

Report Number	Date Tested	Particel Size Distribution Sieve Size										Broken Faces 37.5-19.0 (%)	Broken Faces 19.0-9.5 (%)	Broken Faces 9.5-4.75 (%)	Sand Equivalent	California Bearing Ratio	Crushing Resistance	Cleaness Value	Retained on 4.75 mm sieve	Weathering Quality Index	Plasticity Index	Clay Index
		37.5	19	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075											
BOP15S-00163	27/01/2015	100	81	58	41	31	21	14	10	7	6											
BOP15S-00050	7/01/2015	100	77	51	33	23	15	11	8	6	5	100	100	100	55		5.7	89	93	BB	7	4.5
BOP15S-00691	3/03/2015	100	82	60	40	27	18	13	9	7	5											
BOP15S-00718	6/03/2015	100	78	58	40	28	18	12	9	7	5	100	100	100		190	4.7	91	93	BA	6	4.1
BOP15S-01253	28/04/2015	100	81	54	33	21	14	11	9	7	6	100	100	100	48							
BOP15S-01252	28/04/2015	99	74	52	35	21	14	10	8	6	5	100	100	100			4.7	91	94	BA	6	5.1
BOP15S-01572	27/05/2015	100	72	52	36	25	16	12	9	7	5											
BOP15S-01303	5/05/2015	100	74	50	33	23	16	12	9	8	6	100	100	100	43	305	3.7	85	94	BB	5	5.1
BOP15S-01399	14/05/2015															240						
BOP15S-01613	19/06/2015	100	71	50	33	23	16	11	8	6	5	100	100	100	50							
BOP15S-01803	3/07/2015	100	62	45	33	22	14	9	7	5	4											
BOP15S-01871	17/07/2015	99	73	51	35	25	16	11	8	6	5	100	100	100								
BOP15S-01872	17/07/2015	100	76	53	36	25	17	12	9	6	5	100	100	100								
BOP15S-01791	1/07/2015	100	76	55	38	24	15	11	8	7	6	100	100	100	57	230	4.3	91		BA	16	5
BOP15S-01803	6/01/2015	100	62	45	33	22	14	9	7	5	4											
BOP15S-01871	21/07/2015	99	73	51	35	25	16	11	8	6	5	100	100	100	56							
BOP15S-01872	21/07/2015	100	76	53	36	25	17	12	9	6	5	100	100	100	63							
BOP15S-02154	8/09/2015	100	75	56	39	27	18	13	9	7	6	100	100	100	61	195	4.7	91		BA	9	4.7
BOP15S-02372	14/10/2015	100	76	59	39	27	18	12	9	7	5											
BOP15S-02408	16/10/2015	100	75	53	34	23	15	10	7	5	4											
BOP15S-02491	22/10/2015	100	68	48	31	22	15	11	8	6	5	100	100	100	55							
BOP15S-02492	22/10/2015	100	67	46	30	21	14	10	8	6	5	100	100	100	45		4.4	93		BA	7	4.1
BOP15S-02493	23/10/2015	100	72	54	36	26	17	12	8	6	5	100	100	100	45							
BOP15S-02544	3/11/2015	100	78	59	39	26	16	11	8	6	5	100	100	100	70							
BOP15S-02545	3/11/2015	100	72	52	34	23	15	11	8	6	5	100	100	100	66							
BOP15S-02546	3/11/2015	100	75	57	37	24	15	11	8	6	5	100	100	100	67							
BOP15S-02861	14/12/2015	100	75	54	39	27	17	12	8	6	5											
BOP15S-01521	10/07/2015																	82	92	BB		

I. Appendix I: Results Summary

I.1 T-Grade Results Summary

Table I.1 T-Grade Results Summary

T-Grade	Test Method	Current Specification	Proposed Specification	T1	T2	T3	T4	T5	T6
Source Properties	Weathering resistance	AA, AB, AC, BA, BB or CA	AA, AB, AC, BA, BB or CA	BA	**BC**	BA	BA	BA	BA
	California Bearing Ratio	>80%	>80%	485	325	190	200	245	
	Crushing Resistance	<10% fines passing 2.36mm	<10% fines passing 2.36mm	3.9		*3*	*3.7*	*3.6*	*3.0*
	Ethylene Glycol Testing Crushing Resistance: NZTA approved method	<0.5	<0.5	-0.05	-0.14	**1.69**	0.02	0.56	0.15
Production Properties	Moisture Content	Not specified	Not specified	6.8	6.9	6.7	6.8	6.8	6.7
	Particle Size Distribution 37.5mm	100	100	100	100	100	100	100	100
	19mm	66 - 81	66 - 81	78	77	78	75	75	78
	9.5mm	43 - 57	43 - 57	57	55	56	54	55	58
	4.75mm	28 - 43	28 - 43	36	35	35	35	35	37
	2.36mm	19 - 33	19 - 33	24	25	23	24	23	24
	1.18mm	12 - 25	12 - 25	15	17	16	16	15	16
	600µm	7 - 19	7 - 19	11	12	11	11	11	11

	300µm	3 - 14	3 - 14	8		9		8		8		8		8	
	150µm	0 - 10	0 - 10	6		6		6		6		6		6	
	75µm	0 - 7	0 - 7	5		5		5		5		4		5	
	Sand Equivalent	>40	>40	49		54		59		49		**39**		50	
	Clay Index	<3	<15	**5.4**	**27**	**5.7**	**28.5**	**4.6**	**23**	**4.0**	**20**	**3.7**	**14.8**	**5.2**	**26**
	Methylene Blue Smectite Identification	Not specified	Not specified	6%						6%					
	Plasticity Index	<5	<40	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic
	Broken Faces	>70% & 2 broken faces	>70% & 2 broken faces	100		100		100		100		100		100	
	Sand Grading Exponent (Addition to the draft M/4 2012)	Not specified	>0.04	0.44		0.5		0.46		0.46		0.44		0.46	
Additional Testing	XRD Analysis	Not specified	Not specified	Albite 45%, Augite 30%, Halloysite 25%		Albite 50%, Augite 20%, Halloysite 30%		Albite 55%, Augite 15%, Halloysite 30%		Albite 45%, Augite 25%, Halloysite 30%		Albite 40%, Augite 35%, Halloysite 25%		Albite 45%, Augite 25%, Halloysite 30%	

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Material Test Report

Report No: MAT:CAN15S-12357
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 11/05/2016

Sample Details

Sample ID:	CAN15S-12357
Client Sample ID:	TNZ40-S1
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry, Aggregate made thorugh Trenist Plant at M/4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested:	05/06/2016
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	485	N/A
Moisture Under Plunger (%)		8.1	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		2.06	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		22.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.9	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		95	N/A
Cleanness Value		95	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		9/07/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
NZTA M6:2011 Amendment % Broken Faces			N/A
Clay Index	NZS 4407:2015 Test 3.5	5.4	≤3

Comments

NP = Non Plastic
Date Tested: CI : 07/12/2015, PI: 08/12/2015, Crushing Resistance: 29/11//2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 12/10/2015

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Report No: MAT:CAN15S-12357
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

IANZ

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Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 11/06/2016

Sample Details

Sample ID:	CAN15S-12357
Client Sample ID:	TNZ40-S1
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry , Aggregate made thorugh Trenist Plant at M/4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested:	05/06/2016
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	23	N/A
Sample History		Air -dried	N/A
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 07/12/2015, PI: 08/12/2015, Crushing Resistance: 29/11//2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 12/10/2015

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Material Test Report

Report No: MAT:BOP15S-01627
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

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Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

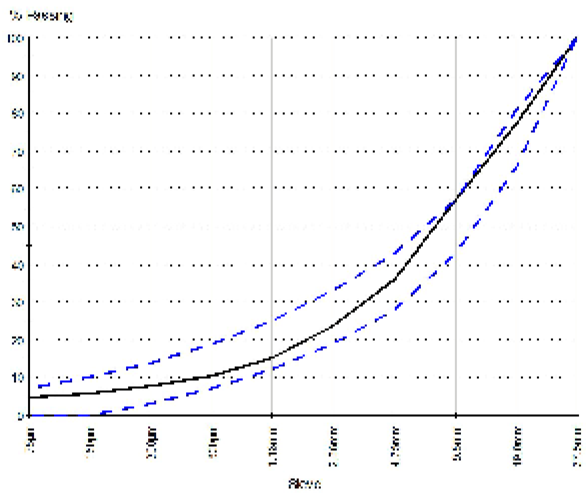
Sample Details

Sample ID:	BOP15S-01627
Client Sample ID:	CAN15S-12357
Material:	TEL - TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	TNZ Rock S/Pile - Sample 1
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	12/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.8	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	49	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	92	N/A
19.0mm	78	66 – 81
9.5mm	57	43 – 57
4.75mm	36	28 – 43
2.36mm	24	19 – 33
1.18mm	15	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	41	28 – 48
9.5mm to 2.36mm	33	14 – 34
4.75mm to 1.18mm	21	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Report No: MAT:CAN15S-12358
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

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Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 11/06/2016

Sample Details

Sample ID:	CAN15S-12358
Client Sample ID:	TNZ40-S2
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry, Aggregate made thorugh Trenist Plant at M4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested:	28/08/2015
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**325**	N/A
Moisture Under Plunger (%)		7.6	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)			N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		23.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BC	N/A
Retained 4.75mm (%)		95	N/A
Cleanness Value		12	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		14/10/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
NZTA M6:2011 Amendment % Broken Faces			N/A
Clay Index	NZS 4407:2015 Test 3.5	5.7	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 11/12/2015, PI: 08/12/2015, Crushing Resistance: 29/11//2015, WQI: 14/10/2015, CBR 28/08/2015, Broken Faces 12/10/2015

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Material Test Report

Report No: MAT:BOP15S-01628
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

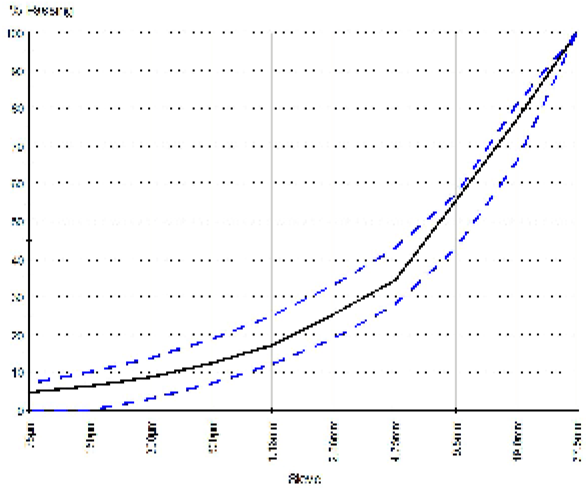
Sample Details

Sample ID:	BOP15S-01628
Client Sample ID:	CAN15S-12358
Material:	TEL - TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	TNZ Rock S/Pile - Sample 2
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	12/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.9	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	54	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	91	N/A
19.0mm	77	66 – 81
9.5mm	55	43 – 57
4.75mm	35	28 – 43
2.36mm	25	19 – 33
1.18mm	17	12 – 25
600µm	12	7 – 19
300µm	9	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	42	28 – 48
9.5mm to 2.36mm	30	14 – 34
4.75mm to 1.18mm	17	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	6	2 – 14

Comments

N/A

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Report No: MAT:CAN15S-12359
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

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Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 21/06/2016

Sample Details

Sample ID:	CAN15S-12359
Client Sample ID:	TNZ40-S3
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Basecourse AP40, Aggregate made through Tranist Plant at M/4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested:	05/06/2016
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	**NZS 4407:2015 Part 3.15**	**190**	N/A
Moisture Under Plunger (%)		7.7	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)			N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		22.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	**NZS 4407:2015 Test 3.10**	3.0	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	**NZS 4407:2015 Test 3.11**	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		91	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		14/10/2015	N/A
Broken Faces 37.5-19.0 (%)	**NZS 4407:2015 Test 3.14**	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	4.6	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	23	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 0312/2015, PI: 07/12/2015, Crushing Resistance: 29/11//2015, WQI: 14/10/2015, CBR 28/08/2015, Broken Faces 12/10/2015

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Report No: MAT:CAN15S-12359
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 21/06/2016

Sample Details

Sample ID:	CAN15S-12359
Client Sample ID:	TNZ40-S3
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Basecourse AP40, Aggregate made through Tranist Plant at M/4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested:	05/06/2016
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 0312/2015, PI: 07/12/2015, Crushing Resistance: 29/11//2015, WQI: 14/10/2015, CBR 28/08/2015, Broken Faces 12/10/2015

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Material Test Report

Report No: MAT:BOP15S-01629
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

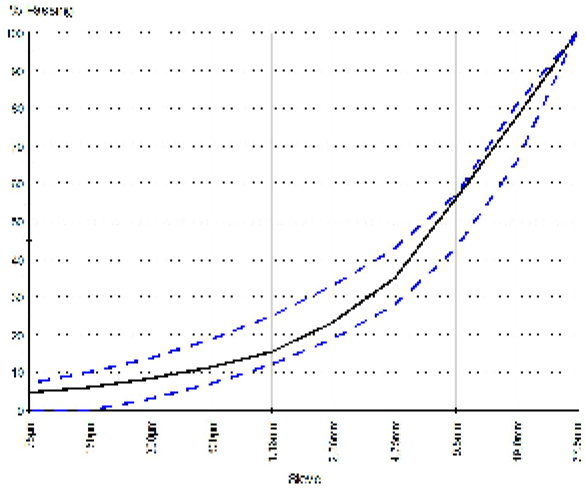
Sample Details

Sample ID:	BOP15S-01629
Client Sample ID:	CAN15S-12359
Material:	TEL - TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	TNZ Rock S/Pile - Sample 3
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	12/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.7	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	59	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	93	N/A
19.0mm	78	66 – 81
9.5mm	56	43 – 57
4.75mm	35	28 – 43
2.36mm	23	19 – 33
1.18mm	16	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	42	28 – 48
9.5mm to 2.36mm	33	14 – 34
4.75mm to 1.18mm	20	7 – 27
2.36mm to 600µm	12	6 – 22
1.18mm to 300µm	7	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Report No: MAT:CAN15S-12360
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 21/06/2016

Sample Details

Sample ID: CAN15S-12360
Client Sample ID: TNZ40-S4
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry Basecourse AP40, Aggregate made through Tranist Plant at M/4 spec
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method: NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested: 28/08/2015
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**200**	N/A
Moisture Under Plunger (%)		6.6	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		1.98	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		25.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.7	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		14/10/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	4.0	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 07/12/2015, PI: 08/12/2015, Crushing Resistance: 29/11//2015, WQI: 14/10/2015, CBR 28/08/2015, Broken Faces 12/10/2015

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Report No: MAT:CAN15S-12360
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
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Project: Quality Assurance Testing

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Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 21/06/2016

Sample Details

Sample ID: CAN15S-12360
Client Sample ID: TNZ40-S4
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry Basecourse AP40, Aggregate made through Transit Plant at M/4 spec
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method: NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested: 28/08/2015
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 07/12/2015, PI: 08/12/2015, Crushing Resistance: 29/11//2015, WQI: 14/10/2015, CBR 28/08/2015, Broken Faces 12/10/2015

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Fulton Hogan

Report No: MAT:BOP15S-01630
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

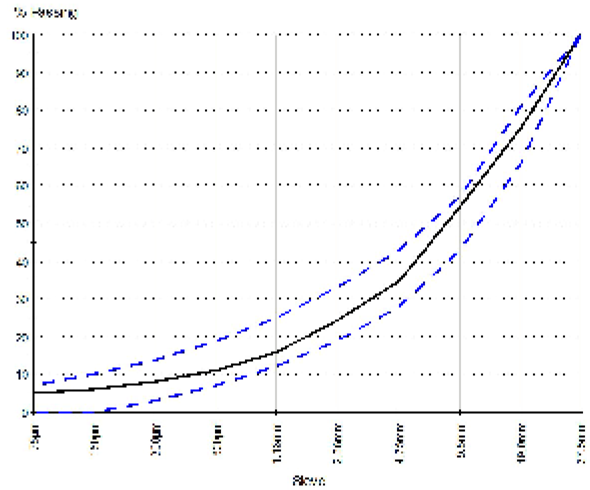
Sample Details

Sample ID:	BOP15S-01630
Client Sample ID:	CAN15S-12360
Material:	TEL - TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	TNZ Rock S/Pile - Sample 4
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	12/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.8	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	49	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	92	N/A
19.0mm	75	66 – 81
9.5mm	54	43 – 57
4.75mm	35	28 – 43
2.36mm	24	19 – 33
1.18mm	16	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	41	28 – 48
9.5mm to 2.36mm	30	14 – 34
4.75mm to 1.18mm	19	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

Fulton Hogan

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Material Test Report

Report No: MAT:CAN15S-12361
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 21/06/2016

Sample Details

Sample ID: CAN15S-12361
Client Sample ID: TNZ40-S5
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry Basecourse AP40, Aggregate made through Tranist Plant at M/4 spec
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method: NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested: 05/06/2016
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**245**	N/A
Moisture Under Plunger (%)		7.5	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.2	N/A
Dry Density After Compaction (t/m³)		2.06	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		23.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.6	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		17/08/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	3.7	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	27	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 07/12/2015, PI: 07/12/2015, Crushing Resistance: 29/11//2015, WQI: 17/08/2015, CBR 31/10/2015, Broken Faces 12/10/2015

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Material Test Report

Report No: MAT:BOP15S-01631
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

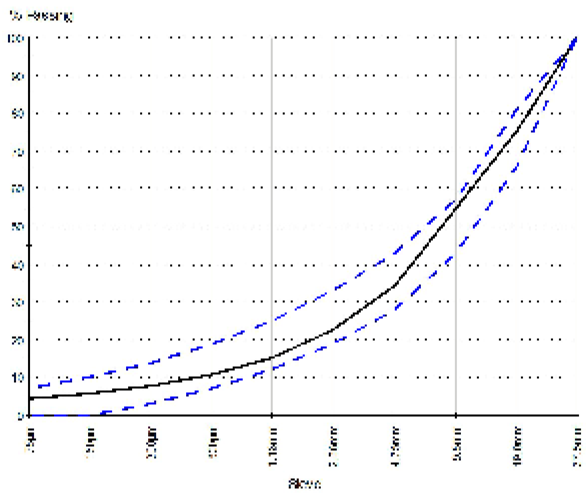
Sample Details

Sample ID:	BOP15S-01631
Client Sample ID:	CAN15S-12361
Material:	TEL - TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	TNZ Rock S/Pile - Sample 5
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	12/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.8	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	39	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	91	N/A
19.0mm	75	66 – 81
9.5mm	55	43 – 57
4.75mm	35	28 – 43
2.36mm	23	19 – 33
1.18mm	15	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	41	28 – 48
9.5mm to 2.36mm	32	14 – 34
4.75mm to 1.18mm	19	7 – 27
2.36mm to 600µm	12	6 – 22
1.18mm to 300µm	7	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Material Test Report

Report No: MAT:CAN15S-12362
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 21/06/2016

Sample Details

Sample ID: CAN15S-12362
Client Sample ID: TNZ40-S6
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry Basecourse AP40, Aggregate made through Transit Plant at M4 spec
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method: NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested: 05/06/2016
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
Fines passing (%)	NZS 4407:2015 Test 3.10	3.0	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		14/10/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.2	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 10/12/2015, PI: 08/12/2015, Crushing Resistance: 29/11//2015, WQI: 14/10/2015, Broken Faces12/10/2015

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Material Test Report

Report No: MAT:BOP15S-01632
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

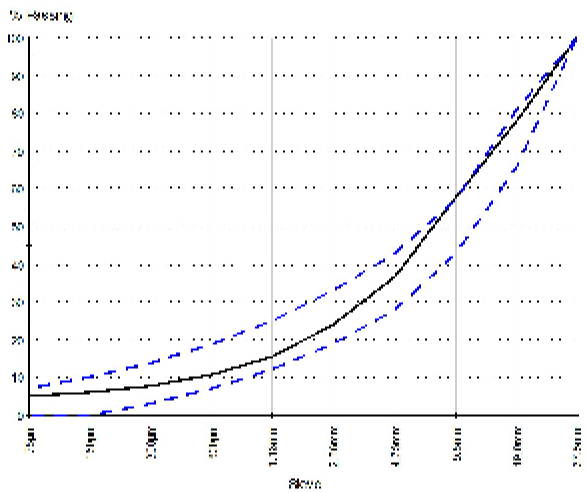
Sample Details

Sample ID:	BOP15S-01632
Client Sample ID:	CAN15S-12362
Material:	TEL - TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	TNZ Rock S/Pile - Sample 6
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	12/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.7	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	50	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	92	N/A
19.0mm	78	66 – 81
9.5mm	58	43 – 57
4.75mm	37	28 – 43
2.36mm	24	19 – 33
1.18mm	16	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	41	28 – 48
9.5mm to 2.36mm	34	14 – 34
4.75mm to 1.18mm	21	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

I.2 C-Grade Results Summary

Table I.2 C-Grade Results Summary

C-Grade	Test Method		Current Specification	Proposed Specification	C1	C2	C3	C4	C5	C6
Source Properties	Weathering resistance		AA, AB, AC, BA, BB or CA	AA, AB, AC, BA, BB or CA	BA	BA	AA	BA	BA	BA
	California Bearing Ratio		>80%	>80%	350	160	220	405	210	
	Crushing Resistance		<10% fines passing 2.36mm	<10% fines passing 2.36mm	*3.2*	*3.1*	*3.1*	*3.2*	*3.7*	*3.5*
	Ethylene Glycol Testing Crushing Resistance: NZTA approved method		<0.5	<0.5	0.06	0.02	**1.53**	-0.04	-0.12	0.15
Production Properties	Moisture Content		Not specified	Not specified	4.9	4.7	4.7	4.8	4.7	4.6
	Particle Size Distribution	37.5mm	100	100	100	100	100	100	100	100
		19mm	66 - 81	66 - 81	81	76	76	72	81	78
		9.5mm	43 - 57	43 - 57	57	55	54	50	58	53
		4.75mm	28 - 43	28 - 43	36	34	35	33	36	33
		2.36mm	19 - 33	19 - 33	24	23	24	22	24	23
		1.18mm	12 - 25	12 - 25	15	15	16	14	15	15
		600µm	7 - 19	7 - 19	11	11	11	10	11	11
		300µm	3 - 14	3 - 14	8	8	8	7	8	7
		150µm	0 - 10	0 - 10	5	5	6	5	6	5
		75µm	0 - 7	0 - 7	4	4	5	4	5	4
	Sand Equivalent		>40	>40	44	49	52	58	62	56

	Clay Index	<3	<15	**5.8**	**23.2**	**5.4**	**21.6**	**5.0**	**25**	**5.2**	**20.8**	**5.9**	**29.5**	**5.0**	**20**
	Methylene Blue Smectite Identification	Not specified	Not specified	4%						4%					
	Plasticity Index	<5	<40	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic	Non Plastic			Non Plastic	Non Plastic
	Broken Faces	>70% & 2 broken faces	>70% & 2 broken faces	100		100		100		100		100		100	
	Sand Grading Exponent (Addition to the draft M/4 2012)	Not specified	>0.04	0.54		0.53		0.46		0.5		0.44		0.54	
Additional Testing	XRD Analysis	Not specified	Not specified	Albite 50%, Augite 20%, Halloysite 30%		Albite 45%, Augite 25%, Halloysite 30%		Albite 40%, Augite 35%, Halloysite 25%		Albite 45%, Augite 25%, Halloysite 30%		Albite 55%, Augite 10%, Halloysite 25%		Albite 55%, Augite 15%, Halloysite 30%	

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Report No: MAT:CAN15S-12363
Issue No: 3
This report replaces all previous issues of report no 'MAT:CAN15S-12363'.

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Daniel Daly
(Lab Technician)
IANZ Accreditation No:200
Date of Issue: 9/11/2016

Sample Details

Sample ID:	CAN15S-12363
Client Sample ID:	C-GRADE C1
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	[illegible]
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	
Date Tested:	
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 2.5mm (%)	NZS 4407:2015 Part 3.15	**350**	N/A
Moisture Under Plunger (%)		5.9	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		1.98	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		22.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.2	N/A
Size of Fraction		-13.2 +9.50mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance			N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		5/06/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.8	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	23	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 09/12/2015, Crushing Resistance: 30/11/2015, WQI: 17/08/2015, CBR 28/08/2015, Broken Faces 09/10/2015

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Material Test Report

Report No: MAT:CAN15S-12363
Issue No: 3
This report replaces all previous issues of report no 'MAT:CAN15S-12363'.

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Daniel Daly
(Lab Technician)
IANZ Accreditation No:200
Date of Issue: 9/11/2016

Sample Details

Sample ID: CAN15S-12363
Client Sample ID: C-GRADE C1
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: [illegible]
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method:
Date Tested:
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 09/12/2015, Crushing Resistance: 30/11/2015, WQI: 17/08/2015, CBR 28/08/2015, Broken Faces 09/10/2015

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Report No: MAT:BOP15S-01633
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 30/06/2015

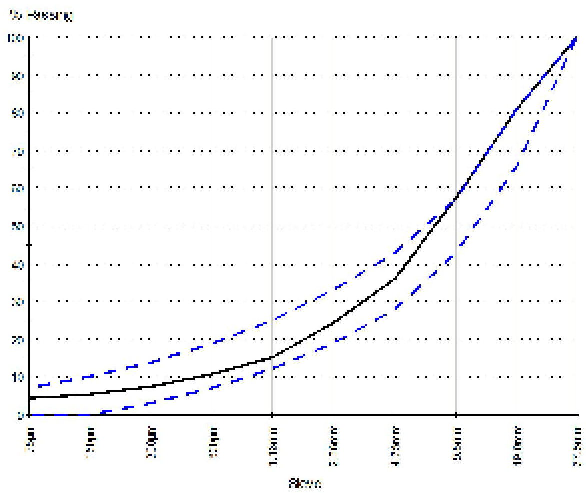
Sample Details

Sample ID:	BOP15S-01633
Client Sample ID:	CAN15S-12363
Material:	Chip 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Chip Rock S/Pile - Sample 1
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.1.2
Date Tested:	15/06/2015
Technician:	William Rodda
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	4.9	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	44	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	94	N/A
19.0mm	81	66 – 81
9.5mm	57	43 – 57
4.75mm	36	28 – 43
2.36mm	24	19 – 33
1.18mm	15	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	5	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	45	28 – 48
9.5mm to 2.36mm	33	14 – 34
4.75mm to 1.18mm	21	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Material Test Report

Report No: MAT:CAN15S-12364
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 9/12/2016

Sample Details

Sample ID:	CAN15S-12364
Client Sample ID:	C-GRADE C2
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry, Aggregate made through Trensit Plant at M4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	
Date Tested:	
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**160**	N/A
Moisture Under Plunger (%)		6.3	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)			N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		22.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.1	N/A
Size of Fraction		-13.2 +9.50mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance			N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		93	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		5/06/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.4	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	23	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 09/12/2015, Crushing Resistance: 29/11/2015, WQI: 17/08/2015, CBR 28/08/2015, Broken Faces 09/11/2015

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Report No: MAT:CAN15S-12364
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID: CAN15S-12364
Client Sample ID: C-GRADE C2
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry, Aggregate made through Trensit Plant at M/4 spec
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method:
Date Tested:
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 09/12/2015, Crushing Resistance: 29/11/2015, WQI: 17/08/2015, CBR 28/08/2015, Broken Faces 09/11/2015

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Fulton Hogan

Report No: MAT:BOP15S-01634
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 30/06/2015

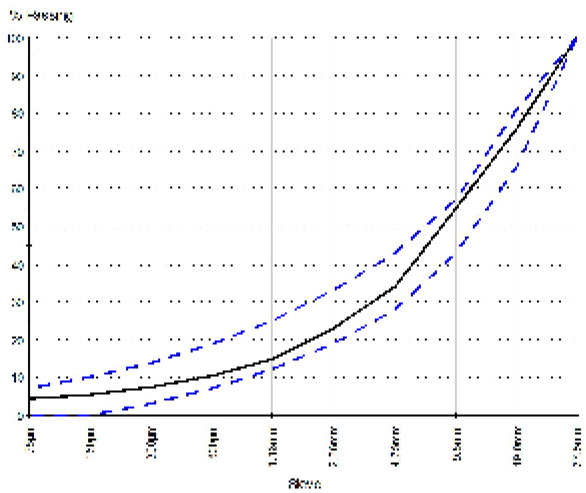
Sample Details

Sample ID:	BOP15S-01634
Client Sample ID:	CAN15S-12364
Material:	Chip 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Chip Rock S/Pile - Sample 2
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.1.2
Date Tested:	16/06/2015
Technician:	William Rodda
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	4.7	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	49	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	92	N/A
19.0mm	76	66 – 81
9.5mm	55	43 – 57
4.75mm	34	28 – 43
2.36mm	23	19 – 33
1.18mm	15	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	5	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	42	28 – 48
9.5mm to 2.36mm	32	14 – 34
4.75mm to 1.18mm	19	7 – 27
2.36mm to 600µm	12	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Material Test Report

Report No: MAT:CAN15S-12365
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID: CAN15S-12365
Client Sample ID: C-GRADE C3
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry, Aggregate made through Trencit Plant at M4 spec
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method:
Date Tested:
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**220**	N/A
Moisture Under Plunger (%)		6.5	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)			N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		24.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.1	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	AA	N/A
Retained 4.75mm (%)		96	N/A
Cleanness Value		95	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		5/06/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.0	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 07/12/2015, Crushing Resistance: 29/11/2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 09/11/2015
Sampling Method: NZS 4407:1991 2.4.6.2.1

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Report No: MAT:CAN15S-12365
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID: CAN15S-12365
Client Sample ID: C-GRADE C3
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry, Aggregate made through Trensit Plant at M4 spec
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method:
Date Tested:
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 07/12/2015, Crushing Resistance: 29/11/2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 09/11/2015
Sampling Method: NZS 4407:1991 2.4.6.2.1

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Report No: MAT:BOP15S-01635
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 30/06/2015

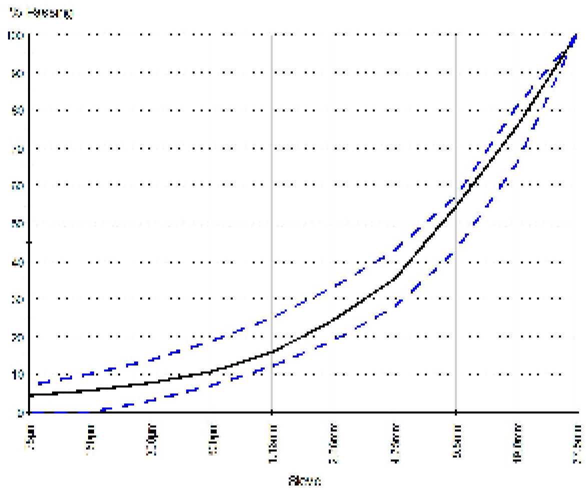
Sample Details

Sample ID:	BOP15S-01635
Client Sample ID:	CAN15S-12365
Material:	Chip 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Chip Rock S/Pile - Sample 3
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.1.2
Date Tested:	16/06/2015
Technician:	William Rodda
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	4.7	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	52	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	91	N/A
19.0mm	76	66 – 81
9.5mm	54	43 – 57
4.75mm	35	28 – 43
2.36mm	24	19 – 33
1.18mm	16	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	40	28 – 48
9.5mm to 2.36mm	30	14 – 34
4.75mm to 1.18mm	20	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Report No: MAT:CAN15S-12366
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12366
Client Sample ID:	C-GRADE C4
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry, Aggregate made through Trenstt Plant at M/4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	
Date Tested:	
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**405**	N/A
Moisture Under Plunger (%)		5.6	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		1.0	N/A
Dry Density After Compaction (t/m³)		1.98	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		28.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.2	N/A
Size of Fraction		-13.2 +9.50mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance			N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		5/06/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.2	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	22	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 07/12/2015, Crushing Resistance: 29/11/2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 09/10/2015
Sampling Method NZS4407:1991 2.4.6.2.1

Canterbury Laboratory

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Material Test Report

Report No: MAT:CAN15S-12366
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12366
Client Sample ID:	C-GRADE C4
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry, Aggregate made through Trencit Plant at M4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	
Date Tested:	
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 07/12/2015, Crushing Resistance: 29/11/2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 09/10/2015
Sampling Method NZS4407:1991 2.4.6.2.1

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Material Test Report

Report No: MAT:BOP15S-01636
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 30/06/2015

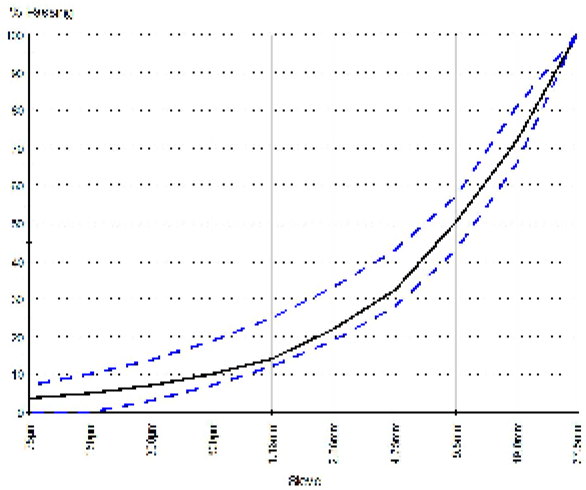
Sample Details

Sample ID:	BOP15S-01636
Client Sample ID:	CAN15S-12366
Material:	Chip 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Chip Rock S/Pile - Sample 4
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.1.2
Date Tested:	16/06/2015
Technician:	William Rodda
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	4.8	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	58	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	88	N/A
19.0mm	72	66 – 81
9.5mm	50	43 – 57
4.75mm	33	28 – 43
2.36mm	22	19 – 33
1.18mm	14	12 – 25
600µm	10	7 – 19
300µm	7	3 – 14
150µm	5	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	39	28 – 48
9.5mm to 2.36mm	28	14 – 34
4.75mm to 1.18mm	18	7 – 27
2.36mm to 600µm	12	6 – 22
1.18mm to 300µm	7	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Fulton Hogan

Report No: MAT:CAN15S-12367
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12367
Client Sample ID:	C-GRADE C5
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry, Aggregate made through Trenolt Plant at M4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	
Date Tested:	
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**210**	N/A
Moisture Under Plunger (%)		6.4	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.2	N/A
Dry Density After Compaction (t/m³)		1.98	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		19.0	N/A
Surcharge Mass (kg)			N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.7	N/A
Size of Fraction		-13.2 +9.50mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance			N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		5/06/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.9	≤3

Comments

Date Tested: CI : 09/12/2015, Crushing Resistance: 30/11/2015, WQI: 17/06/2015, CBR 28/08/2015, Broken Faces 09/10/2015
Sampling Mehtod NZS 4407:1991 2.4.6.2.1

Bay of Plenty Laboratory

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Fulton Hogan

Material Test Report

Report No: MAT:BOP15S-01637
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 30/06/2015

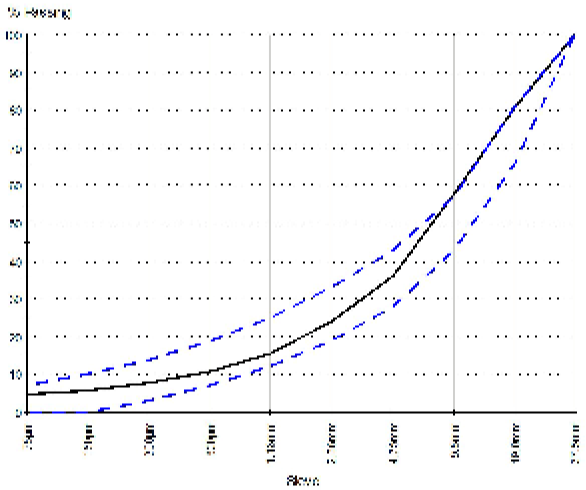
Sample Details

Sample ID:	BOP15S-01637
Client Sample ID:	CAN15S-12367
Material:	Chip 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Chip Rock S/Pile - Sample 5
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.1.2
Date Tested:	16/06/2015
Technician:	William Rodda
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	4.7	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	62	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	95	N/A
19.0mm	81	66 – 81
9.5mm	58	43 – 57
4.75mm	36	28 – 43
2.36mm	24	19 – 33
1.18mm	15	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	44	28 – 48
9.5mm to 2.36mm	34	14 – 34
4.75mm to 1.18mm	21	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

Fulton Hogan

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Material Test Report

Report No: MAT:CAN15S-12368
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2015

Sample Details

Sample ID:	CAN15S-12368
Client Sample ID:	C-GRADE C6
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry, Aggregate made through Trensit Plant at M4 spec
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	
Date Tested:	
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
Fines passing (%)	NZS 4407:2015 Test 3.10	3.5	N/A
Size of Fraction		-13.2 +9.50mm	N/A
Specified Load (kN)		0	N/A
Crushing Resistance			N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		95	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		5/06/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.0	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	21	N/A
Sample History		Air -dried	N/A
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 09/12/2015, PI: 07/12/2015 Crushing Resistance: 01/12/2015, WQI: 14/10/2015,Broken Faces 09/10/2015
Sampling Mehtod NZS 4407:1991 2.4.6.2.1

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Material Test Report

Report No: MAT:BOP15S-01640
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: PLQ Plant Research & Development

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 30/06/2015

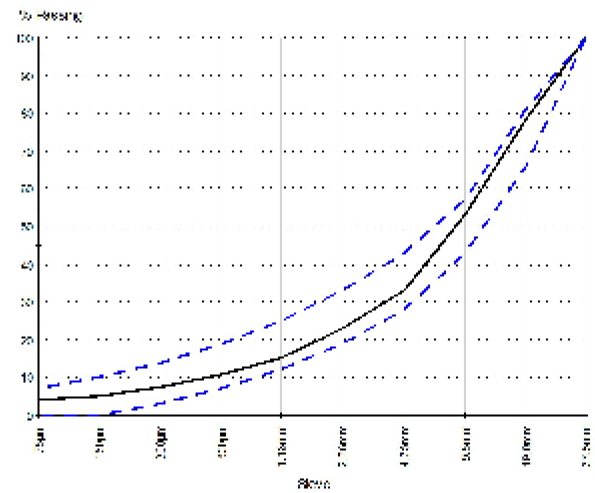
Sample Details

Sample ID:	BOP15S-01640
Client Sample ID:	CAN15S-12368
Material:	Chip 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Chip Rock S/Pile - Sample 6
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.1.2
Date Tested:	17/06/2015
Technician:	William Rodda
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	4.6	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	56	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	91	N/A
19.0mm	78	66 – 81
9.5mm	53	43 – 57
4.75mm	33	28 – 43
2.36mm	23	19 – 33
1.18mm	15	12 – 25
600µm	11	7 – 19
300µm	7	3 – 14
150µm	5	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	45	28 – 48
9.5mm to 2.36mm	30	14 – 34
4.75mm to 1.18mm	18	7 – 27
2.36mm to 600µm	12	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	6	2 – 14

Comments

N/A

I.3 G-Grade Results Summary

Table I.3 G-Grade Results Summary

G-Grade	Test Method	Current Specification	Proposed Specification	G1	G2	G3	G4	G5	G6
Source Properties	Weathering resistance	AA, AB, AC, BA, BB or CA	AA, AB, AC, BA, BB or CA	BA	BA	BA	BB	BB	BA
	California Bearing Ratio	>80%	>80%	250	260	185	155	170	190
	Crushing Resistance	<10% fines passing 2.36mm	<10% fines passing 2.36mm	*4.4*		*3.9*		*3.8*	*4.2*
	Ethylene Glycol Testing Crushing Resistance: NZTA approved method	<0.5	<0.5	0.07		**2.74**		0.16	1.89
Production Properties	Moisture Content	Not specified	Not specified	6.7	6.8	6.9	6.7	6.6	6.8
	Particle Size Distribution 37.5mm	100	100	99	100	100	100	100	100
	19mm	66 – 81	66 - 81	75	77	79	75	79	78
	9.5mm	43 – 57	43 - 57	54	58	57	53	58	59
	4.75mm	28 – 43	28 - 43	35	38	37	35	37	39
	2.36mm	19 – 33	19 - 33	24	27	25	24	25	26

<table>
<tr><td rowspan="12"></td><td>1.18mm</td><td>12 – 25</td><td>12 - 25</td><td colspan="2">16</td><td colspan="2">18</td><td colspan="2">16</td><td colspan="2">15</td><td colspan="2">16</td><td colspan="2">17</td></tr>
<tr><td>600µm</td><td>7 – 19</td><td>7 - 19</td><td colspan="2">11</td><td colspan="2">13</td><td colspan="2">11</td><td colspan="2">11</td><td colspan="2">11</td><td colspan="2">11</td></tr>
<tr><td>300µm</td><td>3 – 14</td><td>3 - 14</td><td colspan="2">8</td><td colspan="2">9</td><td colspan="2">7</td><td colspan="2">7</td><td colspan="2">8</td><td colspan="2">8</td></tr>
<tr><td>150µm</td><td>0 – 10</td><td>0 - 10</td><td colspan="2">6</td><td colspan="2">6</td><td colspan="2">6</td><td colspan="2">5</td><td colspan="2">6</td><td colspan="2">6</td></tr>
<tr><td>75µm</td><td>0 – 7</td><td>0 - 7</td><td colspan="2">5</td><td colspan="2">5</td><td colspan="2">4</td><td colspan="2">4</td><td colspan="2">4</td><td colspan="2">4</td></tr>
<tr><td>Sand Equivalent</td><td>>40</td><td>>40</td><td colspan="2">58</td><td colspan="2">61</td><td colspan="2">48</td><td colspan="2">60</td><td colspan="2">46</td><td colspan="2">54</td></tr>
<tr><td>Clay Index</td><td><3</td><td><15</td><td>5.9</td><td>29.5</td><td>6.0</td><td>30</td><td>6.0</td><td>24</td><td>6.3</td><td>25.2</td><td>6.4</td><td>25.6</td><td>6.0</td><td>24</td></tr>
<tr><td>Methylene Blue Smectite Identification</td><td>Not specified</td><td>Not specified</td><td colspan="6">7%</td><td colspan="6">7%</td></tr>
<tr><td>Plasticity Index</td><td><5</td><td><40</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td><td>Non Plastic</td></tr>
<tr><td>Broken Faces</td><td>>70% & 2 broken faces</td><td>>70% & 2 broken faces</td><td colspan="2">100</td><td colspan="2">100</td><td colspan="2">100</td><td colspan="2">100</td><td colspan="2">100</td><td colspan="2">100</td></tr>
<tr><td>Sand Grading Exponent (Addition to the draft M/4 2012)</td><td>Not specified</td><td>>0.04</td><td colspan="2">0.46</td><td colspan="2">0.53</td><td colspan="2">0.46</td><td colspan="2">0.55</td><td colspan="2">0.46</td><td colspan="2">0.47</td></tr>
<tr><td>XRD Analysis</td><td>Not specified</td><td>Not specified</td><td colspan="2">Albite 90%, Halloysite 10%, Montmorillonite trace</td><td colspan="2">Albite 90%, Halloysite 10%, Montmorillonite trace</td><td colspan="2">Albite 90%, Halloysite 10%, Montmorillonite trace</td><td colspan="2">Albite 90%, Halloysite 10%, Montmorillonite trace</td><td colspan="2">Albite 90%, Halloysite 10%, Montmorillonite trace</td><td colspan="2">Albite 90%, Halloysite 10%, Montmorillonite trace</td></tr>
</table>

Additional Testing (label beside the XRD Analysis row)

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Fulton Hogan

Report No: MAT:CAN15S-12345
Issue No: 2
This report replaces all previous issues of report no 'MAT:CAN15S-12345'.

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID: CAN15S-12345
Client Sample ID: G-Grade - G1
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry stockpile, Sampling method NZS 4407:1991
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method: NZS 4407:1991 2.4.6.2.1
Date Tested: 09/07/2015
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
CBR At 2.5mm (%)	NZS 4407:2015 Part 3.15	**250**	N/A
Moisture Under Plunger (%)		6.8	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		1.98	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		25.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	4.4	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		95	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		17/05/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	5.9	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	25	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 07/12/2015, PI: 09/12/2015, Crushing Resistance: 01/12/2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 05/11/2015

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Material Test Report

Report No: MAT:CAN15S-12345
Issue No: 2
This report replaces all previous issues of report no 'MAT:CAN15S-12345'.

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12345
Client Sample ID:	G-Grade - G1
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry stockpile, Sampling method NZS 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:1991 2.4.6.2.1
Date Tested:	09/07/2015
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 07/12/2015, PI: 09/12/2015, Crushing Resistance: 01/12/2015, WQI: 09/07/2015, CBR 28/08/2015, Broken Faces 05/11/2015

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Report No: MAT:BOP15S-01617
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

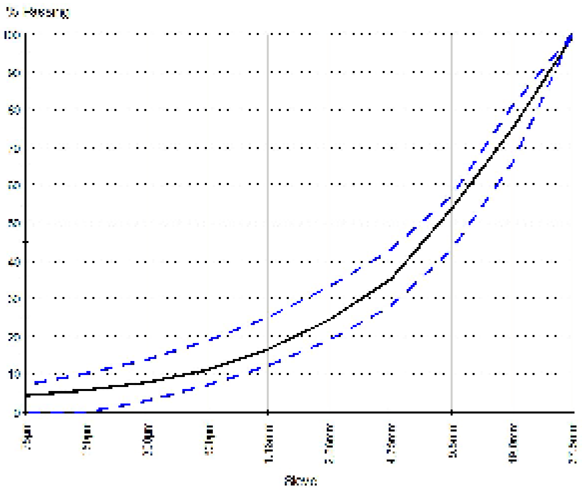
Sample Details

Sample ID:	BOP15S-01617
Client Sample ID:	CAN15S-12345
Material:	GAP 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	GAP Rock S/pile - Sample 1
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	11/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.7	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	58	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	99	100 – 100
26.5mm	91	N/A
19.0mm	75	66 – 81
9.5mm	54	43 – 57
4.75mm	35	28 – 43
2.36mm	24	19 – 33
1.18mm	16	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	40	28 – 48
9.5mm to 2.36mm	29	14 – 34
4.75mm to 1.18mm	19	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	9	5 – 19
600µm to 150µm	6	2 – 14

Comments

N/A

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Fulton Hogan

Report No: MAT:CAN15S-12346
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12346
Client Sample ID:	G-Grade - G2
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Stockpile, Sampling method NZS 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:1991 2.4.6.2.1
Date Tested:	17/08/2015
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 2.5mm (%)	NZS 4407:2015 Part 3.15	**260**	N/A
Moisture Under Plunger (%)		7.4	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		2.04	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		23.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		93	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		17/08/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	6.0	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 10/12/2015, PI: 08/12/2015, WQI: 17/08/2015, CBR 28/08/2015, Broken Faces 05/11/2015

Fulton Hogan

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Report No: MAT:BOP15S-01618
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

IANZ

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

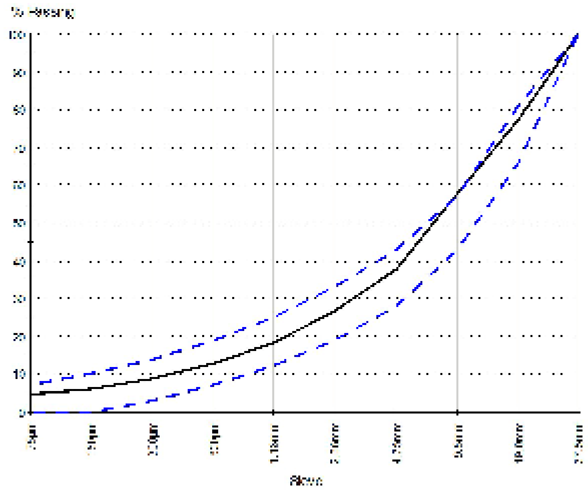
Sample Details

Sample ID:	BOP15S-01618
Client Sample ID:	CAN15S-12346
Material:	GAP 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	GAP Rock S/pile - Sample 2
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	11/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.8	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	61	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	89	N/A
19.0mm	77	66 – 81
9.5mm	58	43 – 57
4.75mm	38	28 – 43
2.36mm	27	19 – 33
1.18mm	18	12 – 25
600µm	13	7 – 19
300µm	9	3 – 14
150µm	6	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	39	28 – 48
9.5mm to 2.36mm	31	14 – 34
4.75mm to 1.18mm	20	7 – 27
2.36mm to 600µm	14	6 – 22
1.18mm to 300µm	9	5 – 19
600µm to 150µm	7	2 – 14

Comments

N/A

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Material Test Report

Report No: MAT:CAN15S-12347
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12347
Client Sample ID:	G-Grade -G3
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Stockpile, Sampling method NZS 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:1991 2.4.6.2.1
Date Tested:	28/08/2016
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	185	N/A
Moisture Under Plunger (%)		7.6	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		1.98	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		21.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.9	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		93	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		14/10/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	6.0	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 08/12/2015, PI: 10/12/2015, Crushing Resistance: 01/12//2015, WQI: 14/10/2015, CBR 28/08/2015, Broken Faces 05/11/2015

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Report No: MAT:CAN15S-12347
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12347
Client Sample ID:	G-Grade -G3
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Stockpile, Sampling method NZS 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:1991 2.4.6.2.1
Date Tested:	28/08/2016
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 08/12/2015, PI: 10/12/2015, Crushing Resistance: 01/12//2015, WQI: 14/10/2015, CBR 28/08/2015, Broken Faces 05/11/2015

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Material Test Report

Report No: MAT:BOP15S-01619
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

IANZ

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

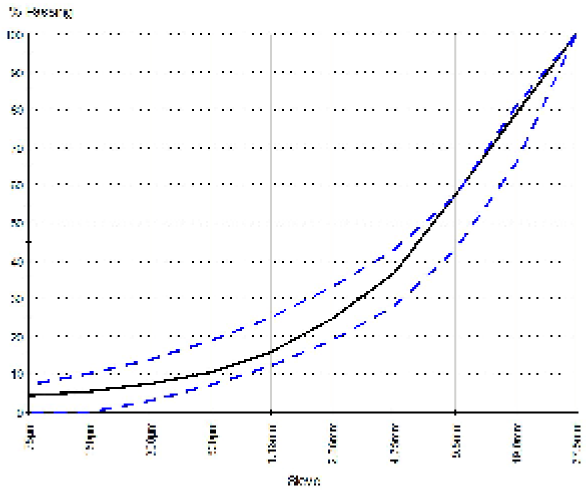
Sample Details

Sample ID:	BOP15S-01619
Client Sample ID:	CAN15S-12347
Material:	GAP 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	GAP Rock S/pile - Sample 3
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	11/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.9	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	48	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	91	N/A
19.0mm	79	66 – 81
9.5mm	57	43 – 57
4.75mm	37	28 – 43
2.36mm	25	19 – 33
1.18mm	16	12 – 25
600µm	11	7 – 19
300µm	7	3 – 14
150µm	6	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	42	28 – 48
9.5mm to 2.36mm	33	14 – 34
4.75mm to 1.18mm	21	7 – 27
2.36mm to 600µm	14	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Fulton Hogan

Report No: MAT:CAN15S-12348
Issue No: 1

Material Test Report

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12348
Client Sample ID:	G-Grade - G4
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Stockpile, Sampling method NZS 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested:	09/07/2015
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	155	N/A
Moisture Under Plunger (%)		7.5	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		2.00	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		25.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BB	N/A
Retained 4.75mm (%)		95	N/A
Cleanness Value		89	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		9/07/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	6.3	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 08/12/2015, PI: 09/12/2015, WQI: 09/07/2015, CBR 31/10/2015, Broken Faces 05/11/2015

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Material Test Report

Report No: MAT:BOP15S-01620
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

IANZ

The test(s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

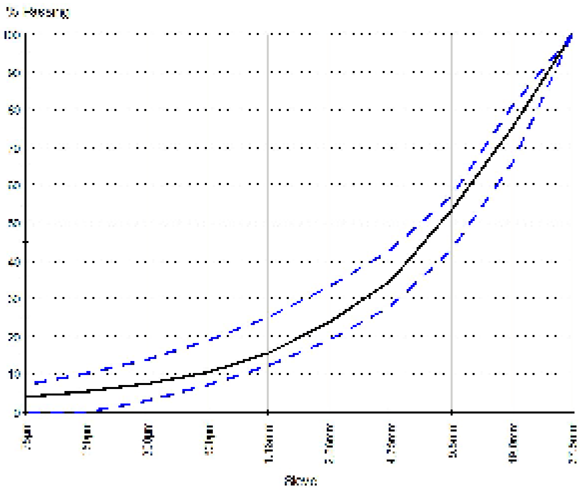
Sample Details

Sample ID:	BOP15S-01620
Client Sample ID:	CAN15S-12348
Material:	GAP 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	GAP Rock S/pile - Sample 4
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	11/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.7	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	60	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	92	N/A
19.0mm	75	66 – 81
9.5mm	53	43 – 57
4.75mm	35	28 – 43
2.36mm	24	19 – 33
1.18mm	15	12 – 25
600µm	11	7 – 19
300µm	7	3 – 14
150µm	5	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	41	28 – 48
9.5mm to 2.36mm	30	14 – 34
4.75mm to 1.18mm	19	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	5	2 – 14

Comments

N/A

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Material Test Report

Report No: MAT:CAN15S-12349
Issue No: 1

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12349
Client Sample ID:	G-Grade - G5
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Stockpile, Sampling Method 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested:	09/07/2015
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:2015 Part 3.15	**170**	N/A
Moisture Under Plunger (%)		8.3	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		2.02	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		21.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	3.8	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BB	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		89	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		9/07/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	6.4	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI : 08/12/2015, PI: 09/12/2015, Crushing Resistance: 30/11//2015, WQI: 09/07/2015, CBR 31/10/2015, Broken Faces 05/11/2015

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Material Test Report

Report No: MAT:CAN15S-12349
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2015

Sample Details

Sample ID: CAN15S-12349
Client Sample ID: G-Grade - G5
Material: TNZ M/4 AP40
Sample Source: BOP - Poplar Lane Quarry
Site/Sampled From: Poplar Lane Quarry Stockpile, Sampling Method 4407:1991
Date Sampled: 22/06/2015
Specification: TNZ M/4:2006 AP40
Sampled By: Clare Dring
Sampling Method: NZS 4407:2015 2.4.6.3.1 (SP/WG/HAND)
Date Tested: 09/07/2015
Technician: Clare Dring
Sampling Endorsed?: No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: CI : 08/12/2015, PI: 09/12/2015, Crushing Resistance: 30/11//2015, WQI: 09/07/2015, CBR 31/10/2015, Broken Faces 05/11/2015

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Report No: MAT:BOP15S-01621
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

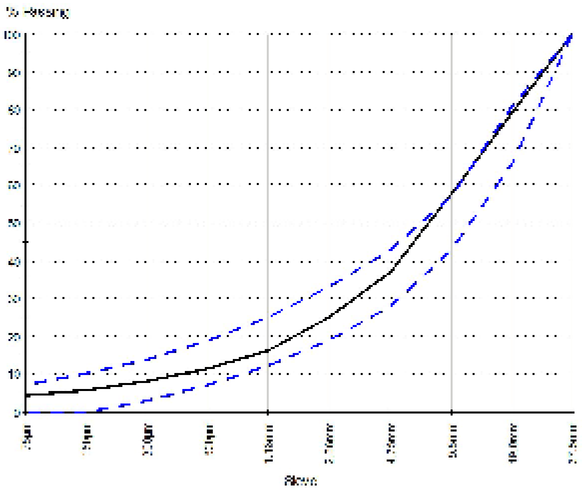
Sample Details

Sample ID:	BOP15S-01621
Client Sample ID:	CAN15S-12349
Material:	GAP 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	GAP Rock S/pile - Sample 5
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	11/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.6	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	46	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	92	N/A
19.0mm	79	66 – 81
9.5mm	58	43 – 57
4.75mm	37	28 – 43
2.36mm	25	19 – 33
1.18mm	16	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	42	28 – 48
9.5mm to 2.36mm	33	14 – 34
4.75mm to 1.18mm	21	7 – 27
2.36mm to 600µm	13	6 – 22
1.18mm to 300µm	8	5 – 19
600µm to 150µm	6	2 – 14

Comments

N/A

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Material Test Report

Report No: MAT:CAN15S-12350
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: Quality Assurance Testing

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12350
Client Sample ID:	G-Grade - G6
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Stockpile, Sampling method NZS 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:1991 2.4.6.2.1
Date Tested:	09/07/2015
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
CBR At 2.5mm (%)	NZS 4407:2015 Part 3.15	190	N/A
Moisture Under Plunger (%)		6.9	N/A
Moisture As Compacted (%)		6.5	N/A
Swell (%)		0.2	N/A
Dry Density After Compaction (t/m³)		2.06	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Oversize Material (%)		22.0	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		5	N/A
Sample History		Natural state	N/A
Fines passing (%)	NZS 4407:2015 Test 3.10	4.2	N/A
Size of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:2015 Test 3.11	BA	N/A
Retained 4.75mm (%)		94	N/A
Cleanness Value		93	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		9/07/2015	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:2015 Test 3.14	100	≥70
Broken Faces 19.0-9.5 (%)		100	≥70
Broken Faces 9.5-4.75 (%)		100	≥70
Clay Index	NZS 4407:2015 Test 3.5	6.0	≤3
Plasticity Index	NZS 4407:2015 3.4	NP	N/A
Plastic Limit	NZS 4407:2015 3.3	NP	N/A
Cone Penetration Limit	NZS 4407:2015 3.2	24	N/A
Sample History		Air -dried	N/A

Comments

NP = Non Plastic
Date Tested: CI: 08/12/2015, PI: 08/12/2015, Crushing Resistance: 01/12//2015, WQI: 09/07/2015, CBR: 31/10/2015, Broken Faces 05/11/2015

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Report No: MAT:CAN15S-12350
Issue No: 1

Material Test Report

Client:	Daniel Topp BOP Poplar Lane Sales Private Bag 12016 Tauranga Mail Centre Tauranga 3143 NZ
Project:	Quality Assurance Testing

The tests reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. Samples are tested as received, in natural condition, unless stated otherwise in the comments. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 22/10/2016

Sample Details

Sample ID:	CAN15S-12350
Client Sample ID:	G-Grade - G6
Material:	TNZ M/4 AP40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	Poplar Lane Quarry Stockpile, Sampling method NZS 4407:1991
Date Sampled:	22/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Clare Dring
Sampling Method:	NZS 4407:1991 2.4.6.2.1
Date Tested:	09/07/2015
Technician:	Clare Dring
Sampling Endorsed?:	No

Test Results

Description	Method	Result	Limits
Test performed on		Fraction passing 425µm sieve	N/A

Comments

NP = Non Plastic
Date Tested: Cl: 08/12/2015, PI: 08/12/2015, Crushing Resistance: 01/12//2015, WQI: 09/07/2015, CBR: 31/10/2015, Broken Faces 05/11/2015

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Material Test Report

Report No: MAT:BOP15S-01622
Issue No: 1

Client: Daniel Topp
BOP Poplar Lane Sales
Private Bag 12016
Tauranga Mail Centre

Tauranga 3143
NZ

Project: PLQ Plant Research & Development

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

Approved Signatory: Rob Ermens
(Lab Manager)
IANZ Accreditation No:749
Date of Issue: 26/06/2015

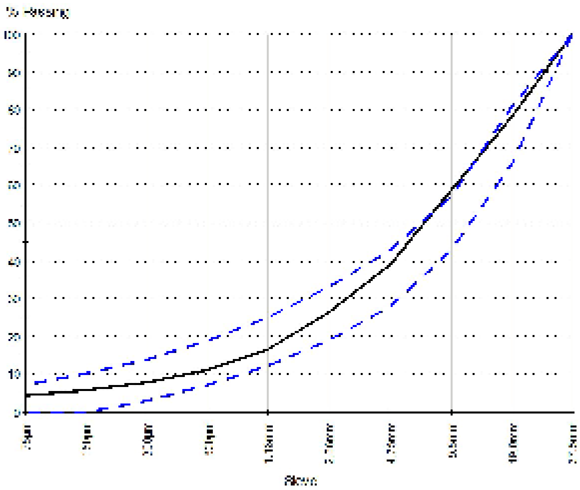
Sample Details

Sample ID:	BOP15S-01622
Client Sample ID:	CAN15S-12350
Material:	GAP 40
Sample Source:	BOP - Poplar Lane Quarry
Site/Sampled From:	GAP Rock S/pile - Sample 6
Date Sampled:	10/06/2015
Specification:	TNZ M/4:2006 AP40
Sampled By:	Barrack Carle
Sampling Method:	NZS 4407:1991 2.4.6.2.2
Date Tested:	12/06/2015
Technician:	Barrack Carle
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	6.8	N/A
Sand Equivalent	NZS 4407:1991 Test 3.6	54	≥40
Shaking Method		Mechanical	N/A

Particle Size Distribution



Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
26.5mm	92	N/A
19.0mm	78	66 – 81
9.5mm	59	43 – 57
4.75mm	39	28 – 43
2.36mm	26	19 – 33
1.18mm	17	12 – 25
600µm	11	7 – 19
300µm	8	3 – 14
150µm	6	0 – 10
75µm	4	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	39	28 – 48
9.5mm to 2.36mm	33	14 – 34
4.75mm to 1.18mm	23	7 – 27
2.36mm to 600µm	15	6 – 22
1.18mm to 300µm	9	5 – 19
600µm to 150µm	6	2 – 14

Comments

N/A

I.4 Control Stone Test Results – Canterbury Greywacke

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Material Test Report

Report No: MAT:CAN16S-00881
Issue No: 1

Client: The Manager
Cant Miners Road
PO Box 16064
Hornby

Christchurch 8441
NZ

Project: QA Testing - Miners Rd Quarry

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 3/02/2016

Sample Details

Sample ID:	CAN16S-00881
Client Sample ID:	M1332
Material:	TNZ M/4 AP40
Sample Source:	Canterbury - #1 Portable Crusher
Site/Sampled From:	Miners Road Quarry
Date Sampled:	14/01/2016
Specification:	TNZ M/4:2006 AP40
Sampled By:	Scott Barwick
Sampling Method:	NZS 4407:1991 2.4.3
Date Tested:	20/01/2016
Technician:	Kurt McBeth
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	2.2	N/A
Fines passing (%)	NZS 4407:1991 Test 3.10	2.1	N/A
Size Of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:1991 Test 3.11	AA	N/A
Retained 4.75mm (%)		96	N/A
Cleanness Value		96	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		3/02/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:1991 Test 3.14	98	≥70
Broken Faces 19.0-9.5 (%)		93	≥70
Broken Faces 9.5-4.75 (%)		87	≥70
Clay Index	NZS 4407:1991 Test 3.5	2.0	≤3
Sand Equivalent	NZS 4407:1991 Test 3.6	34	≥40
Shaking Method		Hand	N/A

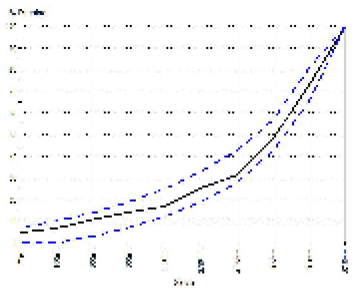
Particle Size Distribution

Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
19.0mm	73	66 – 81
13.2mm	60	N/A
9.5mm	49	43 – 57
6.7mm	38	N/A
4.75mm	32	28 – 43
2.36mm	25	19 – 33
1.18mm	17	12 – 25
600µm	14	7 – 19
300µm	11	3 – 14
150µm	7	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	42	28 – 48
9.5mm to 2.36mm	23	14 – 34
4.75mm to 1.18mm	15	7 – 27
2.36mm to 600µm	11	6 – 22
1.18mm to 300µm	6	5 – 19
600µm to 150µm	7	2 – 14

Chart



Comments

N/A

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Fulton Hogan

Material Test Report

Report No: MAT:CAN16S-00881
Issue No: 1

Client: The Manager
Cant Miners Road
PO Box 16064
Hornby

Christchurch 8441
NZ

Project: QA Testing - Miners Rd Quarry

IANZ

The test (s) reported herein (unless otherwise indicated) have been performed in accordance with the laboratory's scope of accreditation. This report may only be reproduced in full.

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 3/02/2016

Sample Details

Sample ID:	CAN16S-00881
Client Sample ID:	M1332
Material:	TNZ M/4 AP40
Sample Source:	Canterbury - #1 Portable Crusher
Site/Sampled From:	Miners Road Quarry
Date Sampled:	14/01/2016
Specification:	TNZ M/4:2006 AP40
Sampled By:	Scott Barwick
Sampling Method:	NZS 4407:1991 2.4.3
Date Tested:	20/01/2016
Technician:	Kurt McBeth
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
Moisture Content (%)	NZS 4407:1991 Test 3.1	2.2	N/A
Fines passing (%)	NZS 4407:1991 Test 3.10	2.1	N/A
Size Of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:1991 Test 3.11	AA	N/A
Retained 4.75mm (%)		96	N/A
Cleanness Value		96	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		3/02/2016	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:1991 Test 3.14	98	≥70
Broken Faces 19.0-9.5 (%)		93	≥70
Broken Faces 9.5-4.75 (%)		87	≥70
Clay Index	NZS 4407:1991 Test 3.5	2.0	≤3
Sand Equivalent	NZS 4407:1991 Test 3.6	34	≥40
Shaking Method		Hand	N/A

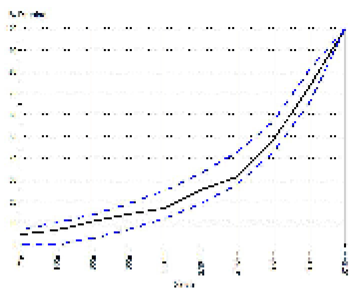
Particle Size Distribution

Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
19.0mm	73	66 – 81
13.2mm	60	N/A
9.5mm	49	43 – 57
6.7mm	38	N/A
4.75mm	32	28 – 43
2.36mm	25	19 – 33
1.18mm	17	12 – 25
600µm	14	7 – 19
300µm	11	3 – 14
150µm	7	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	42	28 – 48
9.5mm to 2.36mm	23	14 – 34
4.75mm to 1.18mm	15	7 – 27
2.36mm to 600µm	11	6 – 22
1.18mm to 300µm	6	5 – 19
600µm to 150µm	7	2 – 14

Chart



Comments

N/A

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Material Test Report

Report No: MAT:CAN14S-21501
Issue No: 1

Client: Andrew Royfee & Blair Ferguson
Cant Miners Road
PO Box 16064
Hornby

Christchurch 8441

Project: QA Testing - Miners Rd Quarry

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IANZ

Approved Signatory: Max Burford
(Supervisor)
IANZ Accreditation No:200
Date of Issue: 29/10/14

Sample Details

Sample ID:	CAN14S-21501
Client Sample ID:	M1110
Material:	TNZ M/4 AP40
Sample Source:	Canterbury - Miners Rd Quarry
Site/Sampled From:	Load Out Face Miners Road
Date Sampled:	15/10/2014
Specification:	TNZ M/4:2006 AP40
Sampled By:	Max Burford
Sampling Method:	NZS 4407:1991 2.4.6.2.1
Date Tested:	20/10/2014
Technician:	Max Burford
Sampling Endorsed?:	Yes

Other Test Results

Description	Method	Result	Limits
CBR At 5.0mm (%)	NZS 4407:1991 Part 3.15	170	N/A
Moisture Under Plunger (%)		5.7	N/A
Moisture As Compacted (%)		5.0	N/A
Swell (%)		0.0	N/A
Dry Density After Compaction (t/m³)		2.28	N/A
Material Used In Test Was		Passing 19.0mm Sieve	N/A
Surcharge Mass (kg)		0.0	N/A
Compactive Effort		Vib.Hammer	N/A
Soaked		Yes	N/A
Period of Soaking (Days)		4	N/A
Rate of Penetration (mm/min)		1.0	N/A
Sample History		Natural state	N/A
Moisture Content (%)	NZS 4407:1991 Test 3.1	2.8	N/A
Fines passing (%)	NZS 4407:1991 Test 3.10	1.3	N/A
Size Of Fraction		-13.2mm, +9.5mm	N/A
Specified Load (kN)		130	N/A
Crushing Resistance		> Specified Load	N/A
Weathering Quality Index	NZS 4407:1991 Test 3.11	AA	N/A
Retained 4.75mm (%)		96	N/A
Cleanness Value		98	N/A
Condition of Sample		Washed/Oven Dried	N/A
Date Tested		29/10/14	N/A
Broken Faces 37.5-19.0 (%)	NZS 4407:1991 Test 3.14	87	≥70
Broken Faces 19.0-9.5 (%)		92	≥70
Broken Faces 9.5-4.75 (%)		81	≥70
Clay Index	NZS 4407:1991 Test 3.5	2.0	≤3
Sand Equivalent	NZS 4407:1991 Test 3.6	37	≥40
Shaking Method		Hand	N/A

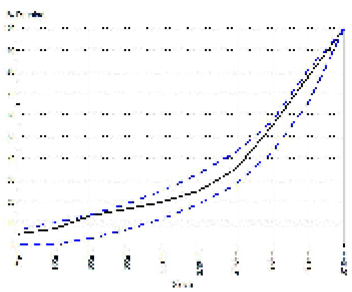
Particle Size Distribution

Method: NZS 4407:1991 Test 3.8.1
Drying by: Oven

Note: Percentage passing the finest sieve was obtained by difference.

Sieve Size	% Passing	Limits
37.5mm	100	100 – 100
19.0mm	78	66 – 81
9.5mm	55	43 – 57
4.75mm	35	28 – 43
2.36mm	25	19 – 33
1.18mm	20	12 – 25
600µm	16	7 – 19
300µm	14	3 – 14
150µm	8	0 – 10
75µm	5	0 – 7
Shape Analysis		N/A
19.0mm to 4.75mm	43	28 – 48
9.5mm to 2.36mm	30	14 – 34
4.75mm to 1.18mm	15	7 – 27
2.36mm to 600µm	9	6 – 22
1.18mm to 300µm	6	5 – 19
600µm to 150µm	9	2 – 14

Chart



Comments

N/A

J. Appendix J: Additional Testing Reports

J.1 Ethylene Glycol Results Method original method

Laboratory Reference: CAN15W2855

CAN15S-12357

Poplar Lane Quarry

TNZ M/4 AP40

Accelerated Weathering - Method Revision 1

Sample T1

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	29/11/2015	3.9
EG Crushing Resistance	11/11/2015	3.71

TEST RESULTS

	Result	**Limit**
Compliance Factor	-0.04	<0.5
Percentage Difference	34	<25%

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Laboratory Reference: **CAN15W2855**
CAN15S-12357

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample T3

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	29/11/2015	3.0
EG Crushing Resistance	19/02/2016	5.0

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.5	<0.5
Percentage Difference	67	<25%

NOTE

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Laboratory Reference: **CAN15W2855**
CAN15S-12360

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample T4

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	29/11/2015	3.7
EG Crushing Resistance	11/11/2015	3.8

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.6	<0.5
Percentage Difference	6	<25%

NOTE

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Laboratory Reference: **CAN15W2855**
CAN15S-12361

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample T5

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	29/11/2015	3.6
EG Crushing Resistance	22/09/2015	5.6

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.6	<0.5
Percentage Difference	56	<25%

NOTE

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Laboratory Reference: **CAN15W2855**
CAN15S-12362

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample T6

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	29/11/2015	3.0
EG Crushing Resistance	11/11/2015	3.8

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.2	<0.5
Percentage Difference	31	<25%

NOTE

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Laboratory Reference: **CAN15W2853**
CAN15S-12345

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample G1

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	01/12/2015	4.4
EG Crushing Resistance	12/11/2015	4.7

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.1	<0.5
Percentage Difference	7 %	<25 %

NOTE

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Laboratory Reference: **CAN15W2853**
CAN15S-12347

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample G3

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	01/12/2015	3.9
EG Crushing Resistance	10/03/2016	7

TEST RESULTS

	Result	**Limit**
Compliance Factor	1.1	<0.5
Percentage Difference	79 %	<25 %

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: **CAN15W2853**
CAN15S-12349

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample G5

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	30/11/2015	3.8
EG Crushing Resistance	11/11/2015	4.5

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.2	<0.5
Percentage Difference	18 %	<25 %

NOTE

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Laboratory Reference: **CAN15W2853**
CAN15S-12350

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample G6

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	01/12/2015	4.2
EG Crushing Resistance	10/03/2016	5.7

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.4	<0.5
Percentage Difference	36 %	<25 %

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: **CAN15W2856**
CAN15S-12363

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample C1

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	30/11/2015	3.2
EG Crushing Resistance	12/11/2015	4.3

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.2	<0.5
Percentage Difference	34	<25%

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: **CAN15W2856**
CAN15S-12364

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample C2

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	29/11/2015	3.1
EG Crushing Resistance	11/12/2015	3.2

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.0	<0.5
Percentage Difference	3	<25%

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: **CAN15W2856**
CAN15S-12365

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample C3

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	19/02/2016	3.1
EG Crushing Resistance	22/09/2015	4.8

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.4	<0.5
Percentage Difference	55 %	<25 %

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: **CAN15W2856**
CAN15S-12366

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample C4

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	29/11/2015	3.2
EG Crushing Resistance	11/11/2015	2.9

TEST RESULTS

	Result	**Limit**
Compliance Factor	-0.04	<0.5
Percentage Difference	-9 %	<25 %

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: **CAN15W2856**
CAN15S-12367

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample C5

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	30/11/2015	3.7
EG Crushing Resistance	12/11/2015	3.3

TEST RESULTS

	Result	**Limit**
Compliance Factor	-0.1	<0.5
Percentage Difference	-11 %	<25 %

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: **CAN15W2856**
CAN15S-12368

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample C6

CLIENT: Polar Lane Quarry
PROJECT: Masters Research
MATERIAL SOURCE: Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM: Laboratory Prepared
SPECIFICATION: NZTA In House Test Method
TEST METHOD USED: Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY: Clare Dring
TESTED BY: Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	01/12/2015	3.5
EG Crushing Resistance	12/11/2015	4.2

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.1	<0.5
Percentage Difference	20 %	<25 %

NOTE

Report Issued By: Clare Dring

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Laboratory Reference:

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample Control 1

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	20/01/2016	2.1
EG Crushing Resistance	10/03/2016	1.8

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.0	<0.5
Percentage Difference	-14%	<25 %

NOTE

Report Issued By: Clare Dring

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Laboratory Reference:

Poplar Lane Quarry
TNZ M/4 AP40
Accelerated Weathering - Method Revision 1
Sample Control 2

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA In House Test Method
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	**Crushing Resistance (%)**
Crushing Resistance	20/10/2014	1.3
EG Crushing Resistance	10/03/2016	2

TEST RESULTS

	Result	**Limit**
Compliance Factor	0.1	<0.5
Percentage Difference	54 %	<25 %

NOTE

Report Issued By: Clare Dring

J.2 NZTA T20 Accelerated Weathering Ethylene Glycol Test Results

Fulton Hogan

Poplar Lane Quarry
TNZ M/4 AP40
Draft NZTA T20 (July 2016)
Ethylene Glycol Accelerated Weathering Test

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	draft NZTA T20
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

Test Results

	CONTROL		**SOAKED**	
Sample	1A	1B	1A	1B
Date tested	01/08/2016	03/08/2016	01/08/2016	01/08/2016
Fraction Size	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm
Specified Load	230kN	230kN	230kN	230kN
Number of days soaked	-	-	21	21
Mass of test specimen (g)	2540	2552	2557	2557
Mass passing 2.36mm sieve (g)	257	237	403	425
Percentage passing	10.1%	9.3%	15.8%	16.6%
Averages	**9.7%**		**16.2%**	

Proportional Change **67%**

Test Report Issued by Clare Dring 05/08/2016

Fulton Hogan

Poplar Lane Quarry
TNZ M/4 AP40
Draft NZTA T20 (July 2016)
Ethylene Glycol Accelerated Weathering Test

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	draft NZTA T20
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

Test Results

	CONTROL PAD A		SOAKED PAD A	
Sample	S2	S4	S1	S3
Date tested	11/09/2016	02/09/2016	02/09/2016	02/09/2016
Fraction Size	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mn
Specified Load	230kN	230kN	230kN	230kN
Number of days soaked	-	-	21	21
Mass of test specimen (g)	2578	2578	2584	2580
Mass passing 2.36mm sieve (g)	252.8	233.3	367	398.2
Percentage passing	9.8%	9.0%	14.2%	15.4%
Averages	9.4%		14.8%	

Proportional Change **57%**

Test Report Issued by Clare Dring 12/09/2016

Fulton Hogan

Poplar Lane Quarry – Test Pad B

TNZ M/4 AP40

Draft NZTA T20 (July 2016)

Ethylene Glycol Accelerated Weathering Test

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	draft NZTA T20
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

Test Results

	CONTROL PAD B		SOAKED PAD B	
Sample	S2	S1	S3	S4
Date tested	06/09/2016	06/09/2016	02/09/2016	02/09/2016
Fraction Size	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm
Specified Load	230kN	230kN	230kN	230kN
Number of days soaked	-	-	21	21
Mass of test specimen (g)	2625	2617	2618	2623
Mass passing 2.36mm sieve (g)	256	206	412.7	423.6
Percentage passing	9.8%	7.9%	15.8%	16.1%
Averages	8.8%		16.0%	

Proportional Change **81%**

Test Report Issued by Clare Dring 12/09/2016

Poplar Lane Quarry – Test Pad C
TNZ M/4 AP40
Draft NZTA T20 (July 2016)
Ethylene Glycol Accelerated Weathering Test

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	draft NZTA T20
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

Test Results

	CONTROL PAD C		SOAKED PAD C	
Sample	S1	S4	S2	S3
Date tested	06/09/2016	06/09/2016	02/09/2016	01/09/2016
Fraction Size	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mn
Specified Load	230kN	230kN	230kN	230kN
Number of days soaked	-	-	21	21
Mass of test specimen (g)	2566	2588	2499	2502
Mass passing 2.36mm sieve (g)	282.3	315.5	420	430.2
Percentage passing	11.0%	12.2%	16.8%	17.2%
Averages	11.6%		17.0%	

Proportional Change **47%**

NOTE: Machine was unable to complete test to 230kN as the maximum displacement was reached.

Test Report Issued by Clare Dring 12/09/2016

Fulton Hogan

Miners Rd – Control Stone
TNZ M/4 AP40
Draft NZTA T20 (July 2016)
Ethylene Glycol Accelerated Weathering Test

CLIENT:	Miners Rd Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Miners Rd Quarry TNZ M/4 AP40
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	draft NZTA T20
TEST METHOD USED:	Accelerated Weathering using the NZS 4407:1994 Test 3.10, *The Crushing Resistance Test*.
PREPARED BY:	Clare Dring
TESTED BY:	Clare Dring

Test Results

	CONTROL UNSOAKED		CONTROL SOAKED	
Sample	C1	C2	S2	S1
Date tested	10/09/2016	11/09/2016	02/09/2016	02/09/2016
Fraction Size	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm	9.5 -13.2 mm
Specified Load	230kN	230kN	230kN	230kN
Number of days soaked	-	-	21	21
Mass of test specimen (g)	2838	2845	2829	2834
Mass passing 2.36mm sieve (g)	147.9	146.1	204.4	209.5
Percentage passing	5.2%	5.1%	7.2%	7.4%
Averages	5.2%		7.3%	

Proportional Change **41%**

Test Report Issued by Clare Dring 12/09/2016

J.3 ITS Test Results

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Laboratory Reference: CAN16W2856
CAN15W-12363

Poplar Lane Quarry
TNZ M/4 AP40 + 1% Cement
ITS Testing – C1

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time A	Time B	Time C	Comment
Sampled	10/06/2015				*Within 2 hours*
Cylinders compacted and rested on bench	26/12/2015	0930	1245	12:00	
Stripped from mould and dimensioned	27/02/2015	1530	1530	11:00	*Harden overnight*
Start of 40°C cure (Bagged with water added)	27/02/2015	1530	1530	11:00	*Target 3 days*
End of 40°C cure and immediately soaked	30/02/2015	0800	0800	09:00	
End of overnight soaking @ ambient	31/02/2015	0900	0900	10:00	*Target 1 day*
Date Tested	31/02/2015	1000	1000	10:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	9.6		
Moisture content as compacted (%)	6.5	6.5	6.5
Bulk density t/m³	**2173**	**2165**	**2165**
ITS kPa	**427**	**296**	**292**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: CAN16W2856
CAN15W-12365

Poplar Lane Quarry
TNZ M/4 AP40 + Cement
ITS Testing – C3 -1.5% Cement

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		*Within 2 hours*
Cylinders compacted and rested on bench	14/01/2016	08:00	
Stripped from mould and dimensioned	15/01/2016	08:00	*Harden overnight*
Start of 40°C cure (Bagged with water added)	15/01/2016	08:00	*Target 3 days*
End of 40°C cure and immediately soaked	18/01/2016	10:00	
End of overnight soaking @ ambient	19/01/2016	09:00	*Target 1 day*
Date Tested	19/01/2016	09:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	10	
	A	**B**
Moisture content as compacted (%)	5.7	5.7
Bulk density t/m³	**2.23**	**2.84**
ITS kPa	**623**	**778**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: CAN16W2856
CAN15W-12364

Poplar Lane Quarry
TNZ M/4 AP40 + Cement
ITS Testing – C2

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time **A-2% Cement**	Time **B – 2% Cement**	Time **C -2% Lime**	Comment
Sampled	10/06/2015				*Within 2 hours*
Cylinders compacted and rested on bench	27/12/2015	10:30	10:30	10:30	
Stripped from mould and dimensioned	28/02/2015	12:00	12:00	12:00	*Harden overnight*
Start of 40°C cure (Bagged with water added)	31/12/2015	12:00	12:00	12:00	*Target 3 days*
End of 40°C cure and immediately soaked	31/02/2015	10:00	10:00	10:00	
End of overnight soaking @ ambient	1/01/2016	11:00	11:00	11:00	*Target 1 day*
Date Tested	1/01/2016	11:00	11:00	11:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	14		
Moisture content as compacted (%)	5.9	5.9	5.9
Bulk density t/m³	**2.19**	**2.14**	**2.15**
ITS kPa	**539**	**412**	**111**

NOTE

Report Issued By:

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Laboratory Reference: CAN16W2855
CAN15W-12358

Poplar Lane Quarry
TNZ M/4 AP40 + Cement
ITS Testing – T2 -1% Cement

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	16/01/2016	13:00	
Stripped from mould and dimensioned	17/01/2016	13:30	*Harden overnight*
Start of 40°C cure (Bagged with water added)	17/01/2016	13:30	*Target 3 days*
End of 40°C cure and immediately soaked	20/01/2016	11:00	
End of overnight soaking @ ambient	21/01/2016	12:00	*Target 1 day*
Date Tested	21/01/2016	12:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	8.3	
	A	**B**
Moisture content as compacted (%)	5.5	5.5
Bulk density t/m³	**2.20**	**2.18**
ITS kPa	**411**	**425**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: CAN16W2855
CAN15W-12357

Poplar Lane Quarry
TNZ M/4 AP40 + Cement
ITS Testing – T1 -1% Cement

CLIENT: Polar Lane Quarry
PROJECT: Masters Research
MATERIAL SOURCE: Poplar Lane QUARRY TNZ M/4 AP40 + 1% cement
SAMPLED FROM: Laboratory Prepared
SPECIFICATION: NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED: NZS 4407:1986 4.1.3 (Vibrating Hammer)
Performed on aggregate passing the 26.5mm sieve
COMPACTED BY: Clare Dring
TESTED BY: Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	01/02/2016	14:00	
Stripped from mould and dimensioned	02/02/2016	12:00	*Harden overnight*
Start of 40°C cure (Bagged with water added)	02/02/2016	12:00	*Target 3 days*
End of 40°C cure and immediately soaked	05/02/2016	13:00	
End of overnight soaking @ ambient	06/02/2016	15:00	*Target 1 day*
Date Tested	06/02/2016	15:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	9	
	A	**B**
Moisture content as compacted (%)	4	4
Bulk density t/m³	**2.21**	**2.23**
ITS kPa	**419**	**387**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference: CAN16W2855
CAN15W-12359

Poplar Lane Quarry
TNZ M/4 AP40 + Cement
ITS Testing – T3 -1% Cement

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane QUARRY TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	02/02/2016	12:30	
Stripped from mould and dimensioned	03/02/2016	12:30	*Harden overnight*
Start of 40°C cure (Bagged with water added)	03/02/2016	12:30	*Target 3 days*
End of 40°C cure and immediately soaked	06/02/2016	15:00	
End of overnight soaking @ ambient	07/02/2016	14:00	*Target 1 day*
Date Tested	07/02/2016	14:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	13	
	A	**B**
Moisture content as compacted (%)	4	4
Bulk density t/m³	**2.20**	**2.14**
ITS kPa	**343**	**275**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference:

Poplar Lane Quarry
TNZ M/4 AP40 with Barmac + Cement
ITS Testing -1% Cement

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane Quarry TNZ M/4 AP40 (with Barmac) + 1% cement
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	22/02/2016	15:00	
Stripped from mould and dimensioned	23/02/2016	14:00	*Harden overnight*
Start of 40°C cure (Bagged with water added)	23/02/2016	14:00	*Target 3 days*
End of 40°C cure and immediately soaked	26/02/2016	13:30	
End of overnight soaking @ ambient	27/02/2016	12:30	*Target 1 day*
Date Tested	27/02/2016	12:30	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	13	
	A	**B**
Moisture content as compacted (%)	5.6	5.6
Bulk density t/m³	**2.20**	**2.24**
ITS kPa	**486**	**374**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference:

Poplar Lane Quarry
TNZ M/4 AP40 with Barmac + Cement
ITS Testing -1% Cement

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane Quarry TNZ M/4 AP40 (with Barmac) + 1% cement
SAMPLED FROM:	Laboratory Prepared
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	22/02/2016	08:00	
Stripped from mould and dimensioned	22/02/2016	15:30	*Harden overnight*
Start of 40°C cure (Bagged with water added)	23/02/2016	14:00	*Target 3 days*
End of 40°C cure and immediately soaked	26/02/2016	13:30	
End of overnight soaking @ ambient	27/02/2016	12:00	*Target 1 day*
Date Tested	27/02/2016	12:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	13		
	A	**B**	**C**
Moisture content as compacted (%)	6.4	6.4	6.4
Bulk density t/m³	2.20	2.20	2.24
ITS kPa	**376**	**501**	**472**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference:

Poplar Lane Quarry
Ethylene Glycol Soaked TNZ M/4 AP40 with Barmac + Cement
ITS Testing -1% Cement

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane Quarry TNZ M/4 AP40 (with Barmac) + 1% cement
SAMPLED FROM:	Laboratory Prepared- Ethylene Glycol Soaked
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	09/03/2016	10:00	
Stripped from mould and dimensioned	10/03/2016	12:30	*Harden overnight*
Start of 40°C cure (Bagged with water added)	10/03/2016	12:30	*Target 3 days*
End of 40°C cure and immediately soaked	13/03/2016	13:30	
End of overnight soaking @ ambient	14/03/2016	14:00	*Target 1 day*
Date Tested	14/03/2016	14:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	11		
	A	**B**	**C**
Moisture content as compacted (%)	6.4	6.4	6.4
Bulk density t/m³	2.26	2.28	2.29
ITS kPa	**60**	**123**	**136**

NOTE

Report Issued By: Clare Dring

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Laboratory Reference:

Miners Rd Quarry
Ethylene Glycol Soaked TNZ M/4 AP40 + Cement
ITS Testing -1% Cement

CLIENT:	Miners Rd Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Miners Rd Quarry TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared- Ethylene Glycol Soaked
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer)
	Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	13/03/2016	08:00	
Stripped from mould and dimensioned	14/03/2016	09:00	*Harden overnight*
Start of 40°C cure (Bagged with water added)	14/03/2016	09:00	*Target 3 days*
End of 40°C cure and immediately soaked	17/03/2016	16:00	
End of overnight soaking @ ambient	18/03/2016	15:00	*Target 1 day*
Date Tested	18/03/2016	15:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	8		
	A	**B**	**C**
Moisture content as compacted (%)	4.2	4.2	4.2
Bulk density t/m³	2.35	2.26	2.22
ITS kPa	**164**	**116**	**124**

NOTE

Report Issued By: Clare Dring

Fulton Hogan

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0800 LABORATORY

Laboratory Reference:

Poplar Lane Quarry
Ethylene Glycol Soaked TNZ M/4 AP40 + Cement
ITS Testing -1% Cement

CLIENT:	Polar Lane Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Poplar Lane Quarry TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared- Ethylene Glycol Soaked
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	15/03/2016	07:00	
Stripped from mould and dimensioned	16/03/2016	10:00	*Harden overnight*
Start of 40°C cure (Bagged with water added)	16/03/2016	10:00	*Target 3 days*
End of 40°C cure and immediately soaked	19/03/2016	14:00	
End of overnight soaking @ ambient	20/03/2016	13:00	*Target 1 day*
Date Tested	20/03/2016	13:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	13		
	A	**B**	**C**
Moisture content as compacted (%)	6.4	6.4	6.4
Bulk density t/m³	2.24	2.24	2.19
ITS kPa	**154**	**152**	**125**

NOTE

Report Issued By: Clare Dring

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0800 LABORATORY

Laboratory Reference:

Miners Rd Quarry
Ethylene Glycol Soaked TNZ M/4 AP40 + Cement
ITS Testing -1% Cement

CLIENT:	Miners Rd Quarry
PROJECT:	Masters Research
MATERIAL SOURCE:	Miners Rd Quarry TNZ M/4 AP40 + 1% cement
SAMPLED FROM:	Laboratory Prepared- Ethylene Glycol Soaked
SPECIFICATION:	NZTA Draft T/19 version 6 (ITS) tested at 1mm per minute
TEST METHOD USED:	NZS 4407:1986 4.1.3 (Vibrating Hammer) Performed on aggregate passing the 26.5mm sieve
COMPACTED BY:	Clare Dring
TESTED BY:	Clare Dring

	Date	Time	Comment
Sampled	10/06/2015		
Cylinders compacted and rested on bench	12/03/2016	11:00	
Stripped from mould and dimensioned	13/03/2016	09:30	*Harden overnight*
Start of 40°C cure (Bagged with water added)	13/03/2016	09:30	*Target 3 days*
End of 40°C cure and immediately soaked	16/03/2016	14:00	
End of overnight soaking @ ambient	17/03/2016	15:00	*Target 1 day*
Date Tested	17/03/2016	15:00	

TEST RESULTS

Fraction passing 26.5mm sieve removed (%)	8		
	A	**B**	**C**
Moisture content as compacted (%)	4.2	4.2	4.2
Bulk density t/m³	2.27	2.29	2.28
ITS kPa	**142**	**169**	**140**

NOTE

Report Issued By: Clare Dring

K. Appendix K: Thin Section Summary

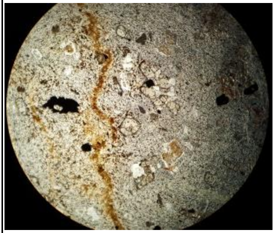
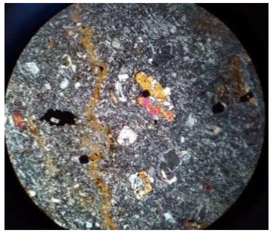
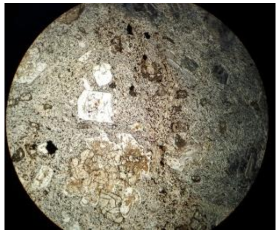
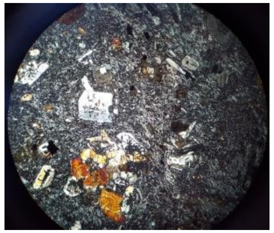
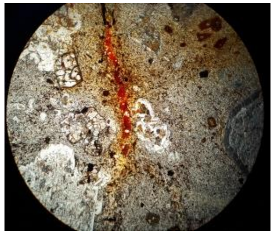
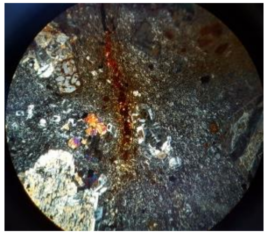
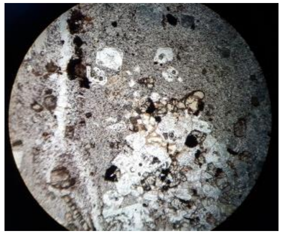
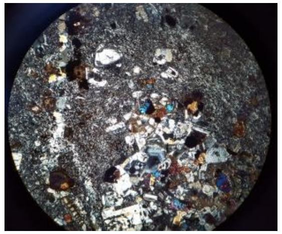
K.1 T-Grade Thin Section Samples – Before Crushing

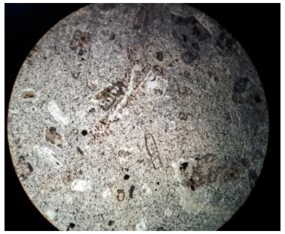
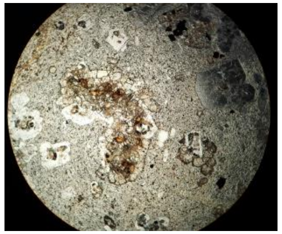
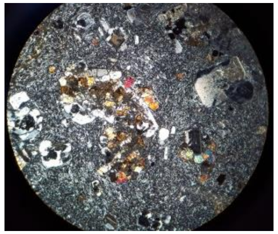
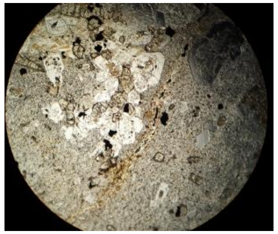
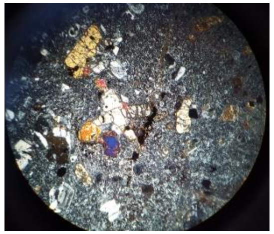
Table K.1 T-Grade Thin Section Samples – Before Crushing

Name	Source	Details	Description	Mineralogy	Percentage	Features
TB-1	T-Grade Before Crushing 1	Andesite	Micro Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	40%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Subhedral - Anhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic
				Iron Oxide	3%	Staining
TB-3	T-Grade Before Crushing 3	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	40%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	35%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	3%	Cubic
				Iron Oxide	2%	Staining

TB-5	T-Grade Before Crushing 5	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	50%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	20%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	8%	Cubic and Hexagonal
				Iron Oxide	5%	Staining

Table K.2 T-Grade Thin Section Images- Before Crushing

Name	**Images**
TB-1	   
TB-3	   

TB-5	     

K.2 T-Grade Thin Section Samples – After Crushing

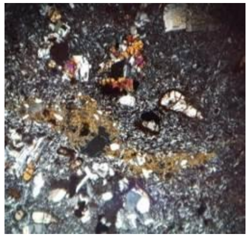
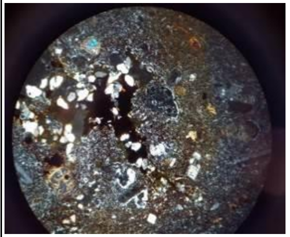
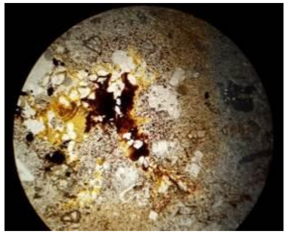
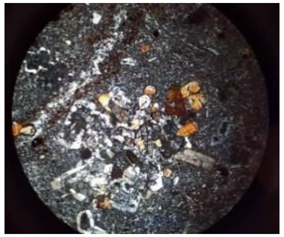
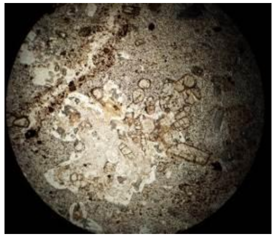
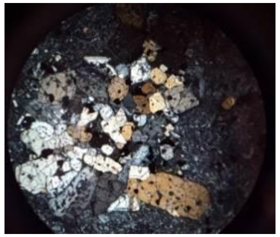
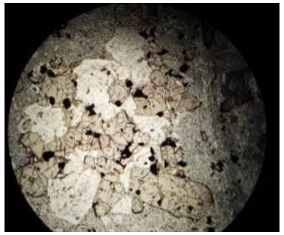
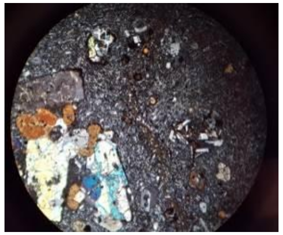
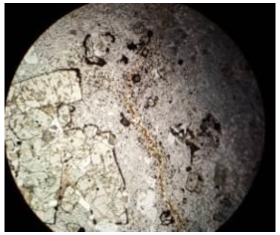
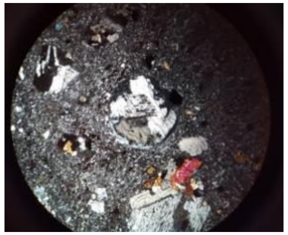
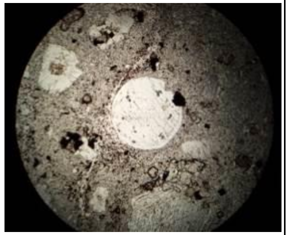
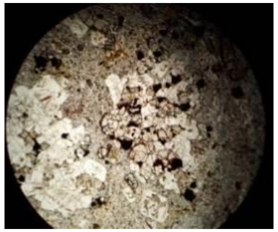
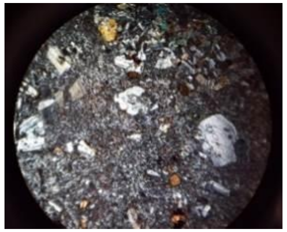
Table K.3 T-Grade Thin Section Samples – After Crushing

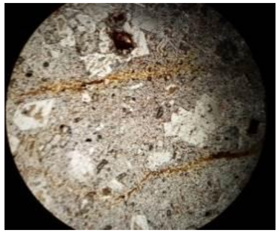
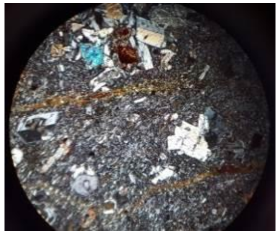
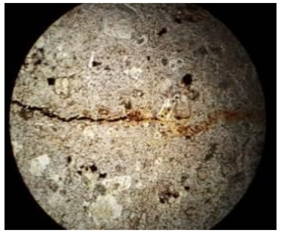
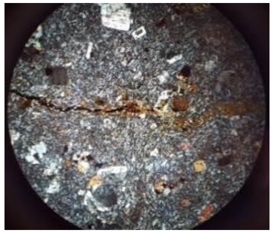
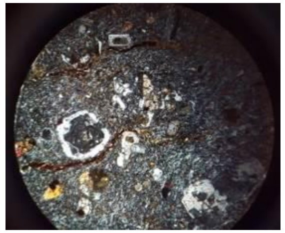
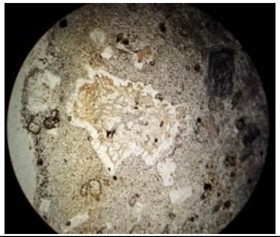
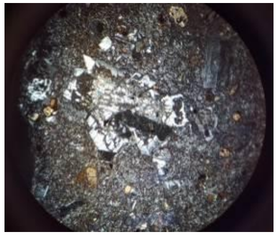
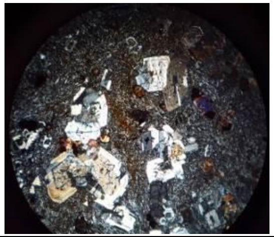
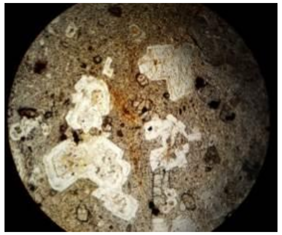
Name	Source	Details	Description	Mineralogy	Percentage	Textures
TA-1	T-Grade After Crushing 1	Andesite	Micro Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	35%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Subhedral - Anhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques and Opaques	7%	Cubic and Hexagonal
				Iron Oxide	2%	Staining
TA-2	T-Grade After Crushing 2	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	25%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Subhedral - Anhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	10%	Cubic and Hexagonal

				Iron Oxide	10%	Staining
TA-3	T-Grade After Crushing 3	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	35%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	20%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	3%	Cubic and Hexagonal
				Iron Oxide	2%	Staining
TA-4	T-Grade After Crushing 4	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	10%	Cubic and Hexagonal
				Iron Oxide	0%	Staining
TA-5	T-Grade After Crushing 5	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution

				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	11%	Subhedral - Anhedral,
				Glass and Opaques	8%	Cubic and Hexagonal
				Red -brown	1%	looks like water throughout thin section
				Iron Oxide	5%	Staining
TA-6	T-Grade After Crushing 6	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic.	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	5%	Staining

Table K.4 T-Grade Thin Section Images - After Crushing

Name	Images
TA-1	     
TA-2	   
TA-3	     
TA-4	  

TA-5	     
TA-6	   

K.3 C-Grade Thin Section Samples – Before Crushing

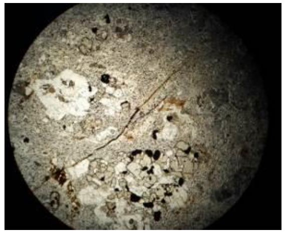
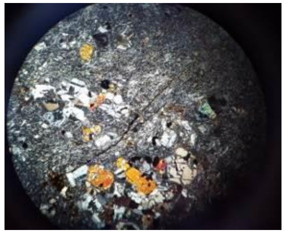
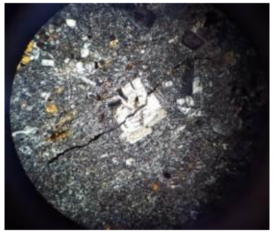
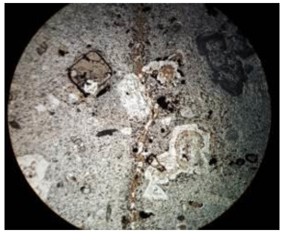
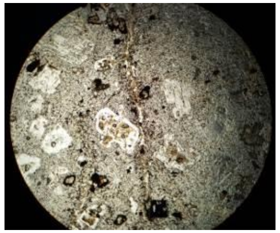
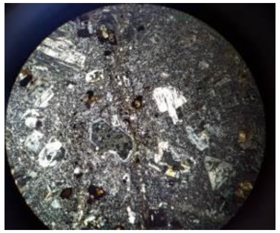
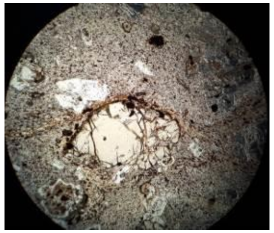
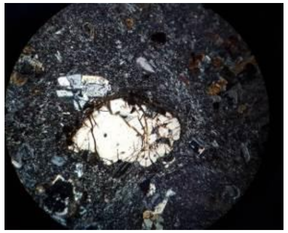
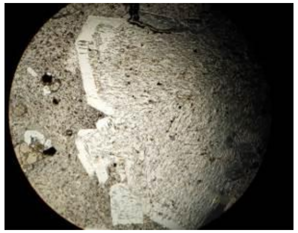
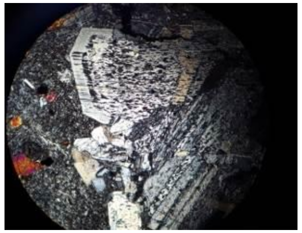
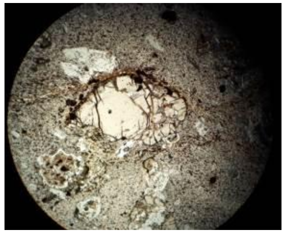
Table K.5 C-Grade Thin Sections - Before Crushing

Name	Source	Details	Description	Mineralogy	Percentage	Textures
CB-1	C-Grade Before Crushing 1	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Micro-vein infilled with K-Feldspar and Plagioclase Feldspar	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	12%	Subhedral - Anhedral,
				Glass and Opaques	7%	Cubic and Hexagonal
				Iron Oxide	2%	Staining
CB-2	C-Grade Before Crushing 2	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic.	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	12%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	2%	Staining
CB-3	C-Grade Before	Andesite	Micro-veins/ Alteration Micro-veins,	Ground Mass	40%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,

	Crushing 3		Glomeroporphyritic, Porphyritic, Aphanitic.	K-Feldspar and Plagioclase Feldspar 3-4mm	35%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	13%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	7%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	3%	Staining
CB-5	C-Grade Before Crushing 5	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic.	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	35%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	5%	Staining
CB-6	C-Grade Before Crushing 6	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic.	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,

				Glass and Opaques	8%	Cubic and Hexagonal
				Iron Oxide	2%	Staining- infilling in Micro-veins

Table K.6 C-Grade Thin Section Images - Before Crushing

Name	Images
CB-1	   
CB-2	   
CB-3	    

K.4 C-Grade Thin Section Samples – After Crushing

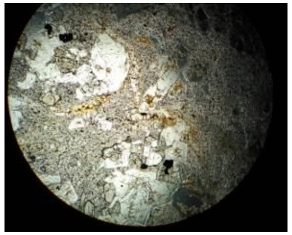
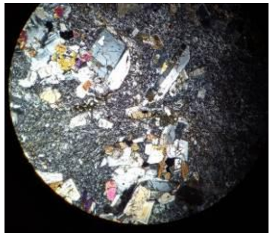
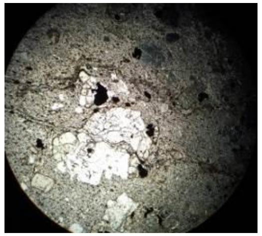
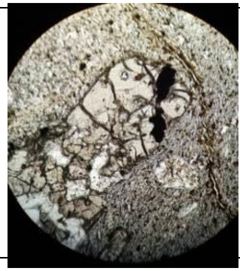
Table K.7 C-Grade Thin Section Samples - After Crushing

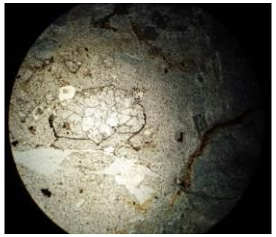
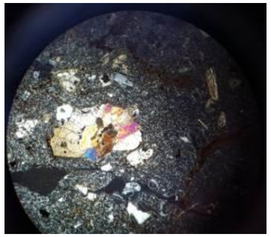
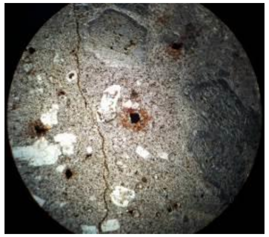
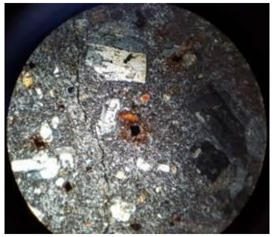
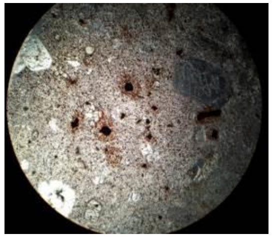
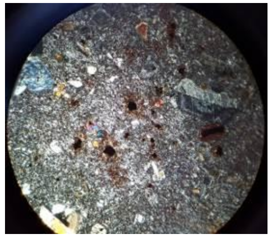
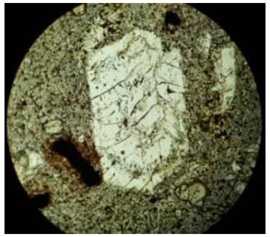
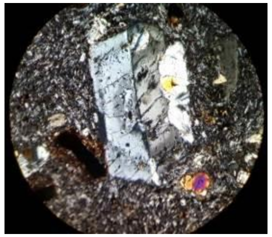
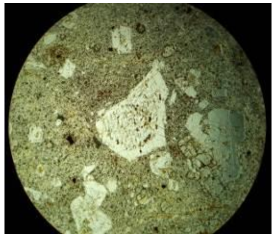
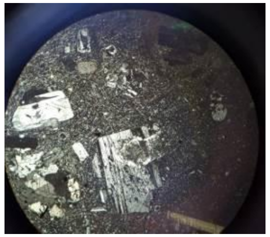
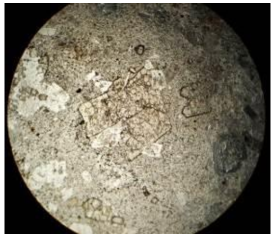
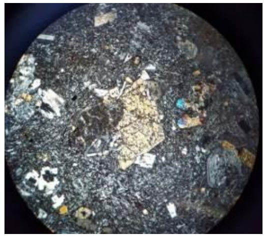
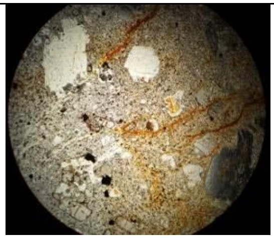
Name	Source	Details	Description	Mineralogy	Percentage	Textures
CA-1	C-Grade After Crushing 1	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Micro-vein infilled with K-Feldspar and Plagioclase Feldspar	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	13%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	2%	Staining
CA-2	C-Grade After Crushing 2	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic.	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	13%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	2%	Staining
CA-3	C-Grade After Crushing 3	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic,	Ground Mass	37%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth,

			Porphyritic, Aphanitic.	Feldspar 3-4mm		regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	3%	Staining
CA-4	C-Grade After Crushing 4	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Micro Micro-veins	Ground Mass	40%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	32%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	8%	Subhedral - Anhedral,
				Glass and Opaques	5%	Suuronded by Iron staining
				Iron Oxide	5%	Staining
CA-5	C-Grade After Crushing 5	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic.	Ground Mass	45%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	35%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	10%	Staining

CA-6	C-Grade After Crushing 6	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic.	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	8%	Cubic and Hexagonal
				Iron Oxide	2%	Staining- infilling in Micro-veins

Table K.8 C-Grade Thin Section Images - After Crushing

Name	Images
CA-1	   
CA-2	     

CA-3	     
CA-4	   
CA-5	 
CA-6	

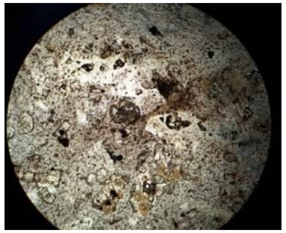
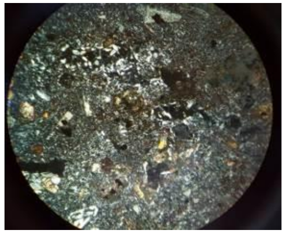
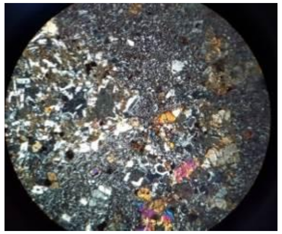
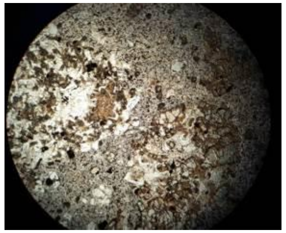
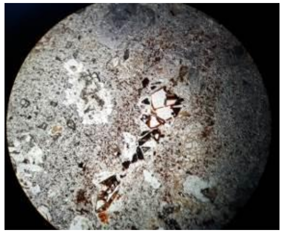
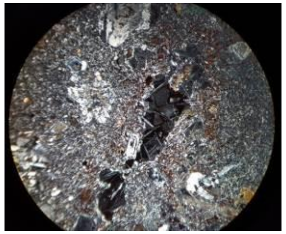
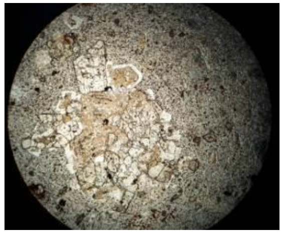
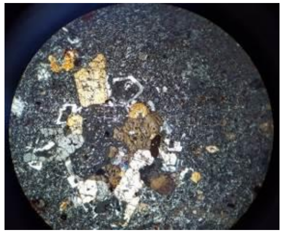
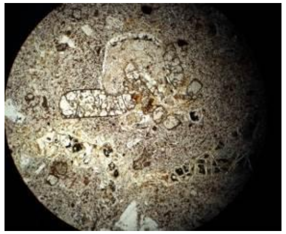
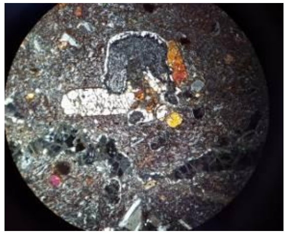
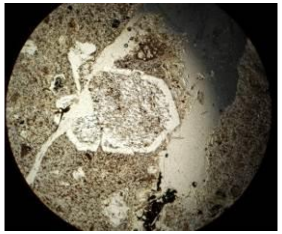
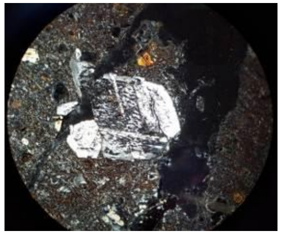
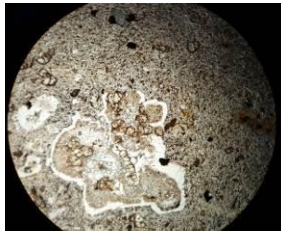
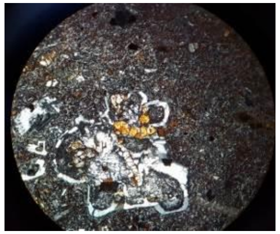
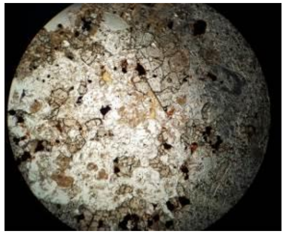
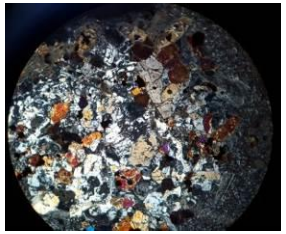
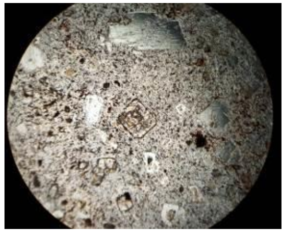
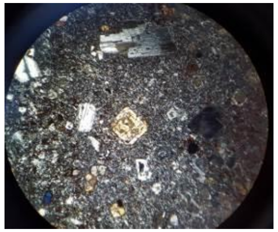
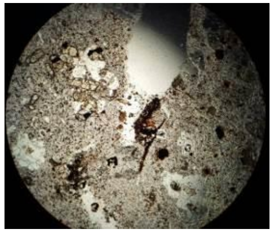
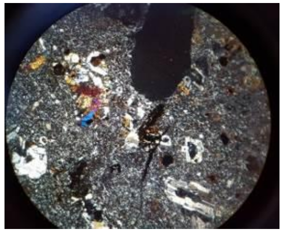
K.5 G-Grade Thin Section Samples – Before Crushing

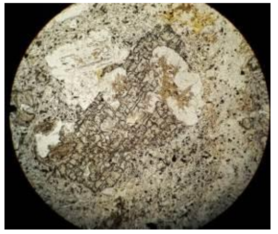
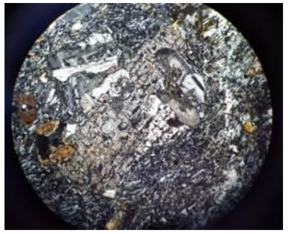
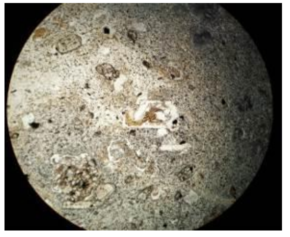
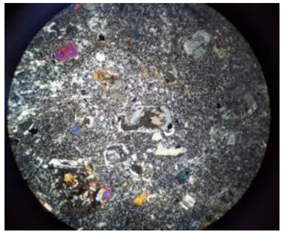
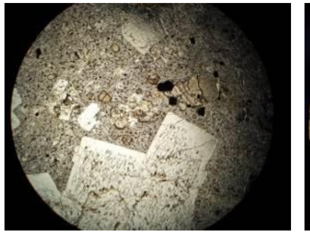
Table K.9 G-Grade Thin Section Samples - Before Crushing

Name	Source	Details	Description	Mineralogy	Percentage	Textures
GB-1	G-Grade Before Crushing 1	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Micro-veins filled with needle like crystals	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	8%	Subhedral - Anhedral,
				Glass and Opaques	10%	Cubic and Hexagonal
				Iron Oxide	2%	Staining- infilling in Micro-veins
GB-3	G-Grade Before Crushing 3	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins G-Gradeing 2-3mm (no filling)	Ground Mass	40%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-5mm	25%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	10%	Cubic and Hexagonal
				Iron Oxide	2%	Staining- infilling in Micro-veins

GB-4	G-Grade Before Crushing 4	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins G-Gradeing 2-3mm (no filling)	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	3%	Staining - in and around "Micro-veins"
GB-6	G-Grade Before Crushing 6	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins G-Gradeing 2-3mm (no filling)	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	10%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	2%	

Table K.10 G-Grade Thin Section Images - Before Crushing

Name	Images
GB-1	   
GB-3	   
GB-4	     
GB-6	     

CB-5	 
CB-6	   

K.6 G-Grade Thin Section Samples – After Crushing

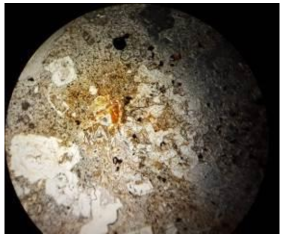
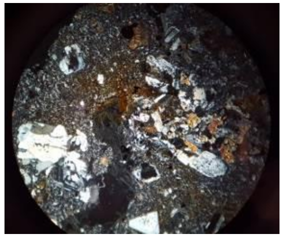
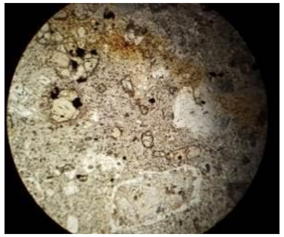
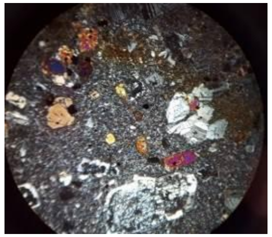
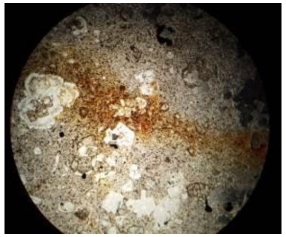
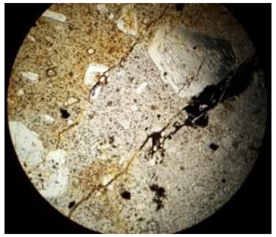
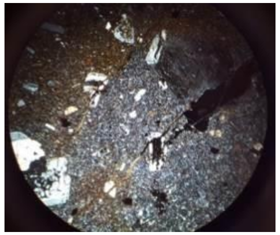
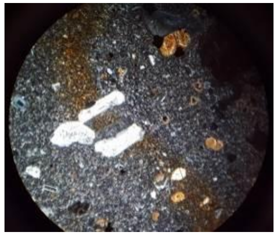
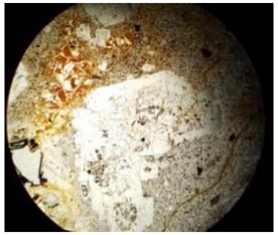
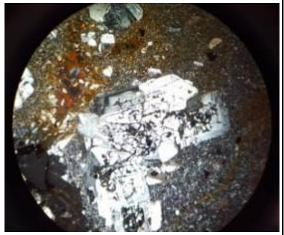
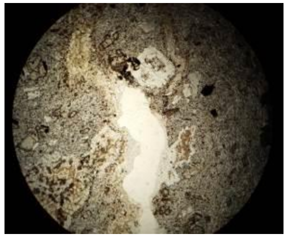
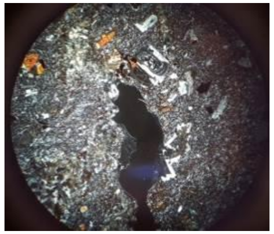
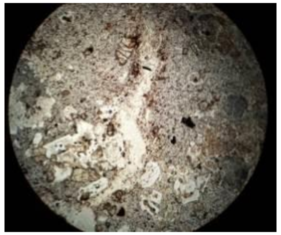
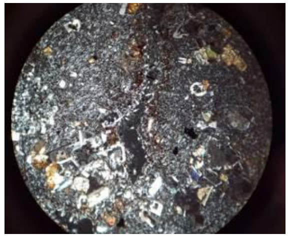
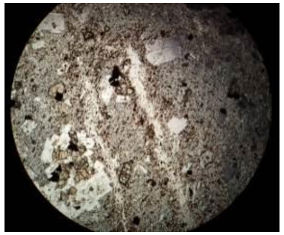
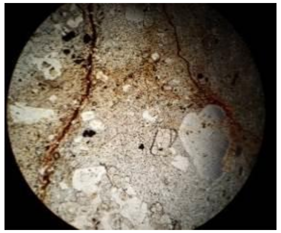
Table K.11 G-Grade Thin Section Samples - After Crushing

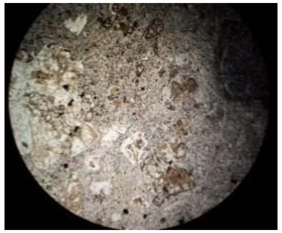
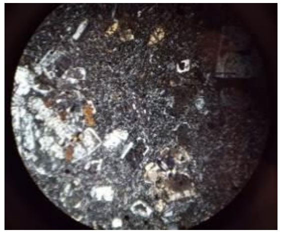
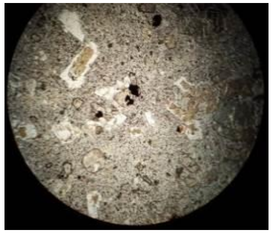
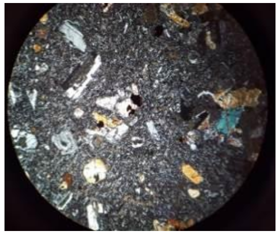
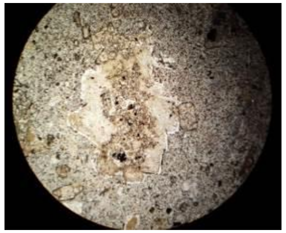
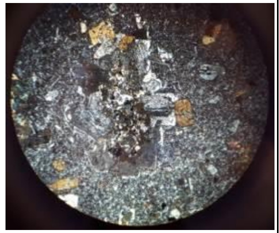
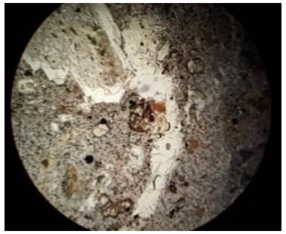
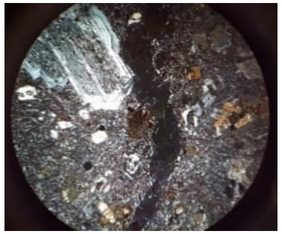
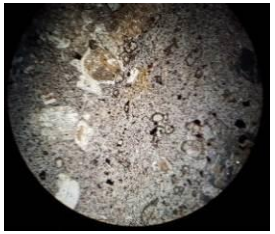
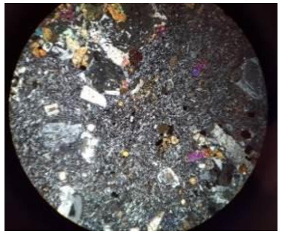
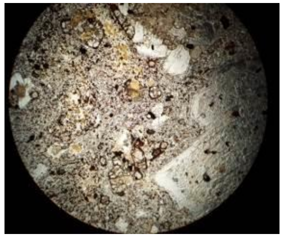
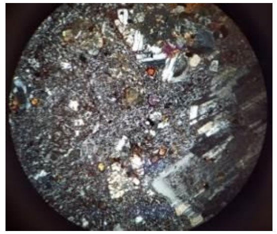
Name	Source	Details	Description	Mineralogy	Percentage	Textures
GA-1	GAP After Crushing 1	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Micro-veins filled with needle like crystals	Ground Mass	35%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	7%	Subhedral - Anhedral,
				Glass and Opaques	6%	Cubic and Hexagonal
				Iron Oxide	2%	Staining- infilling in Micro-veins
GA-2	GAP After Crushing 2	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins gaping 2-3mm (no filling)	Ground Mass	40%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	10%	Staining- infilling in Micro-veins

GA-3	GAP After Crushing 3	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins gaping 2-3mm (no filling)	Ground Mass	45%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-5mm	25%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	15%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	8%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	2%	Staining- infilling in Micro-veins
GA-4	GAP After Crushing 4	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins gaping 2-3mm (no filling)	Ground Mass	30%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	40%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	10%	Staining - in and around "Micro-veins"
GA-5	GAP After Crushing 5	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins gaping	Ground Mass	45%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	30%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution

			2-3mm (no filling)	Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	5%	Subhedral - Anhedral,
				Glass and Opaques	8%	Cubic and Hexagonal
				Iron Oxide	2%	
GA-6	GAP After Crushing 6	Andesite	Micro-veins/ Alteration Micro-veins, Glomeroporphyritic, Porphyritic, Aphanitic. Large Micro-veins gaping 2-3mm (no filling)	Ground Mass	50%	Microcrystalline, Fine grained, Hypocrystalline, Elongate -K-Feldspar and Plagioclase Feldspar,
				K-Feldspar and Plagioclase Feldspar 3-4mm	25%	Euhedral -Subhedral, twinned, some zoned, intergrowth, regrowth, dissolution
				Orthopyroxene	10%	Euhedral - Subhedral,
				Augite (Clinopyroxene)	6%	Subhedral - Anhedral,
				Glass and Opaques	5%	Cubic and Hexagonal
				Iron Oxide	2%	

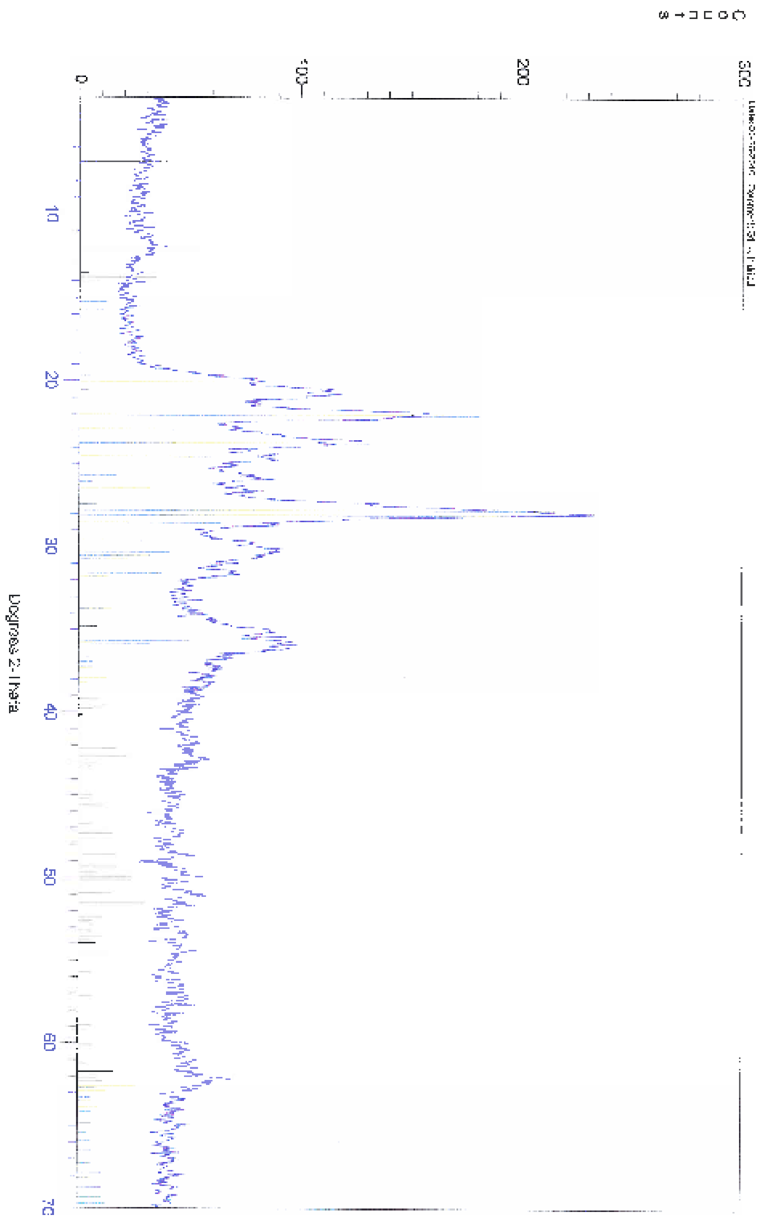
Table K.12 G-Grade Thin Section images - After Crushing

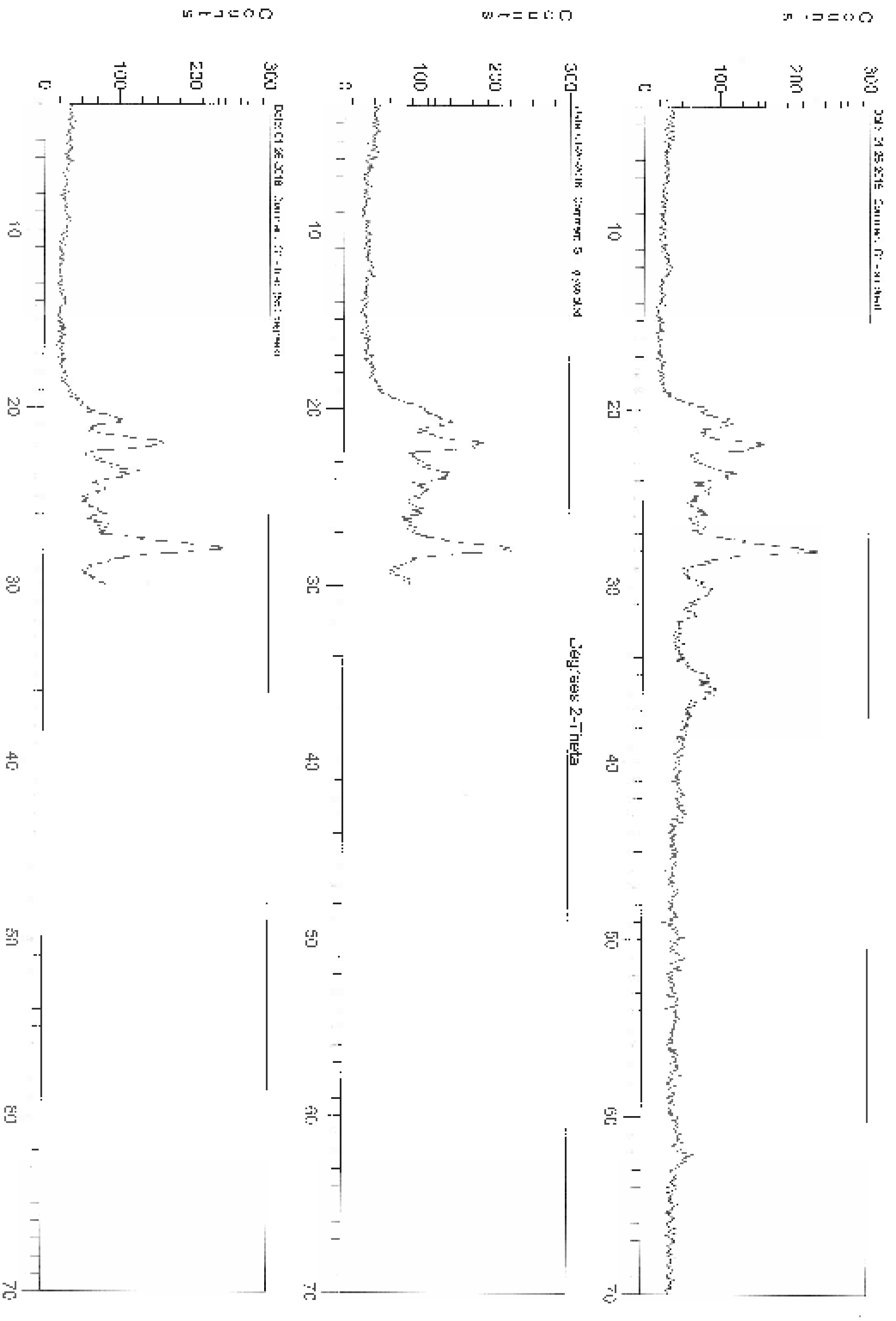
Name	Images
GA-1	    
GA-2	     
GA-3	     
GA-4	  

GA-5	     
GA-6	     

L. Appendix L: XRD Results

L.1G-Grade XRD Spectrums

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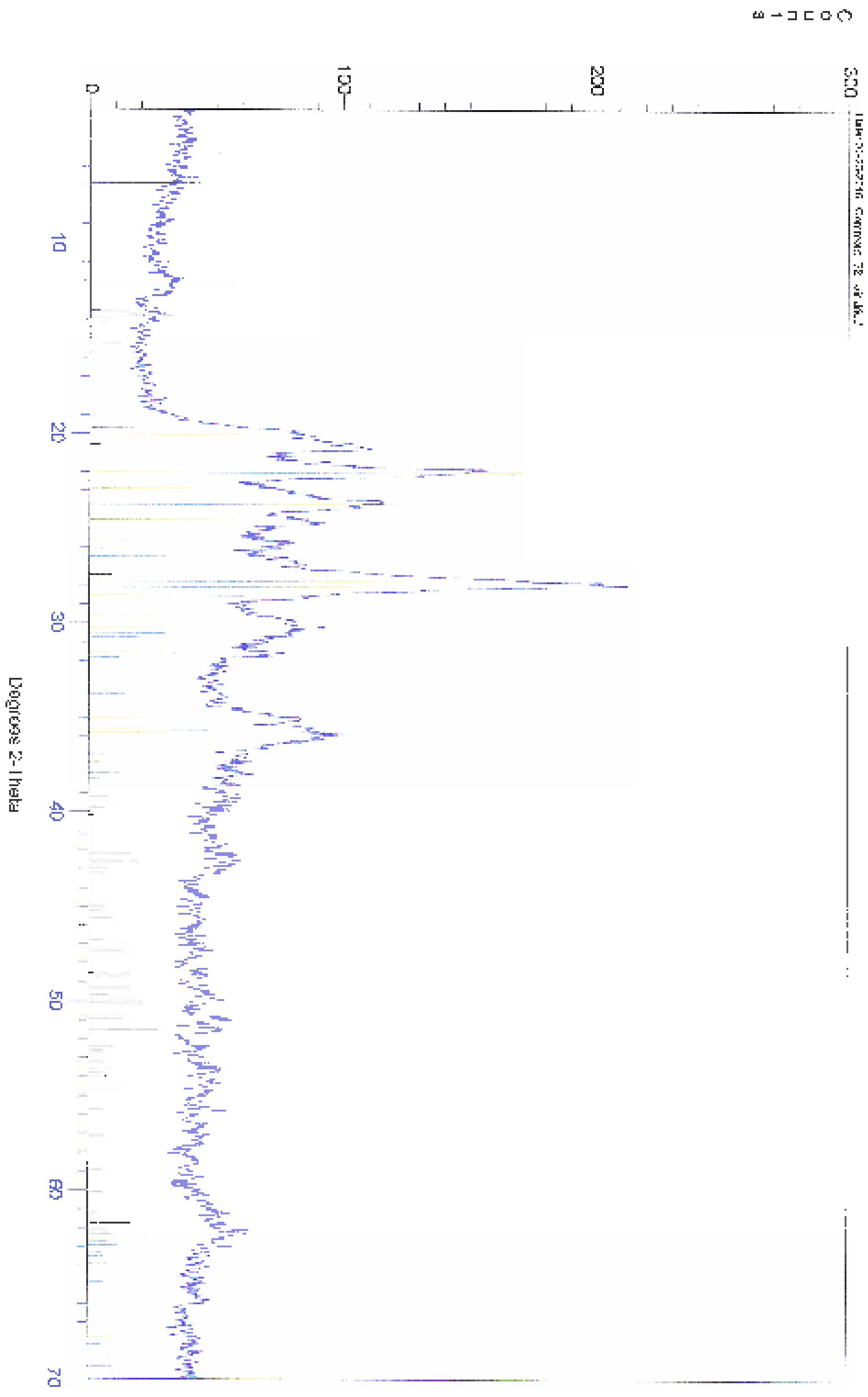
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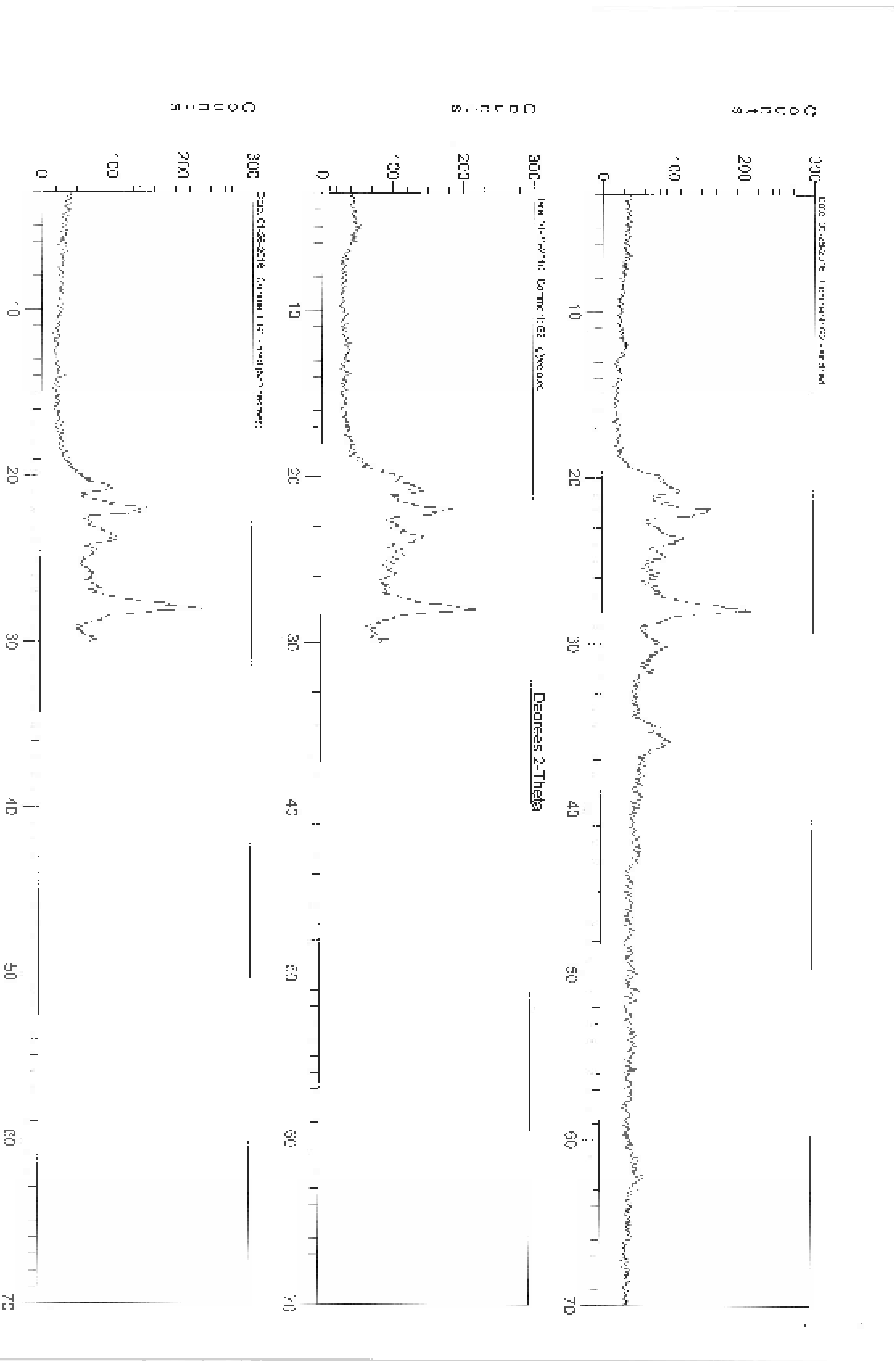
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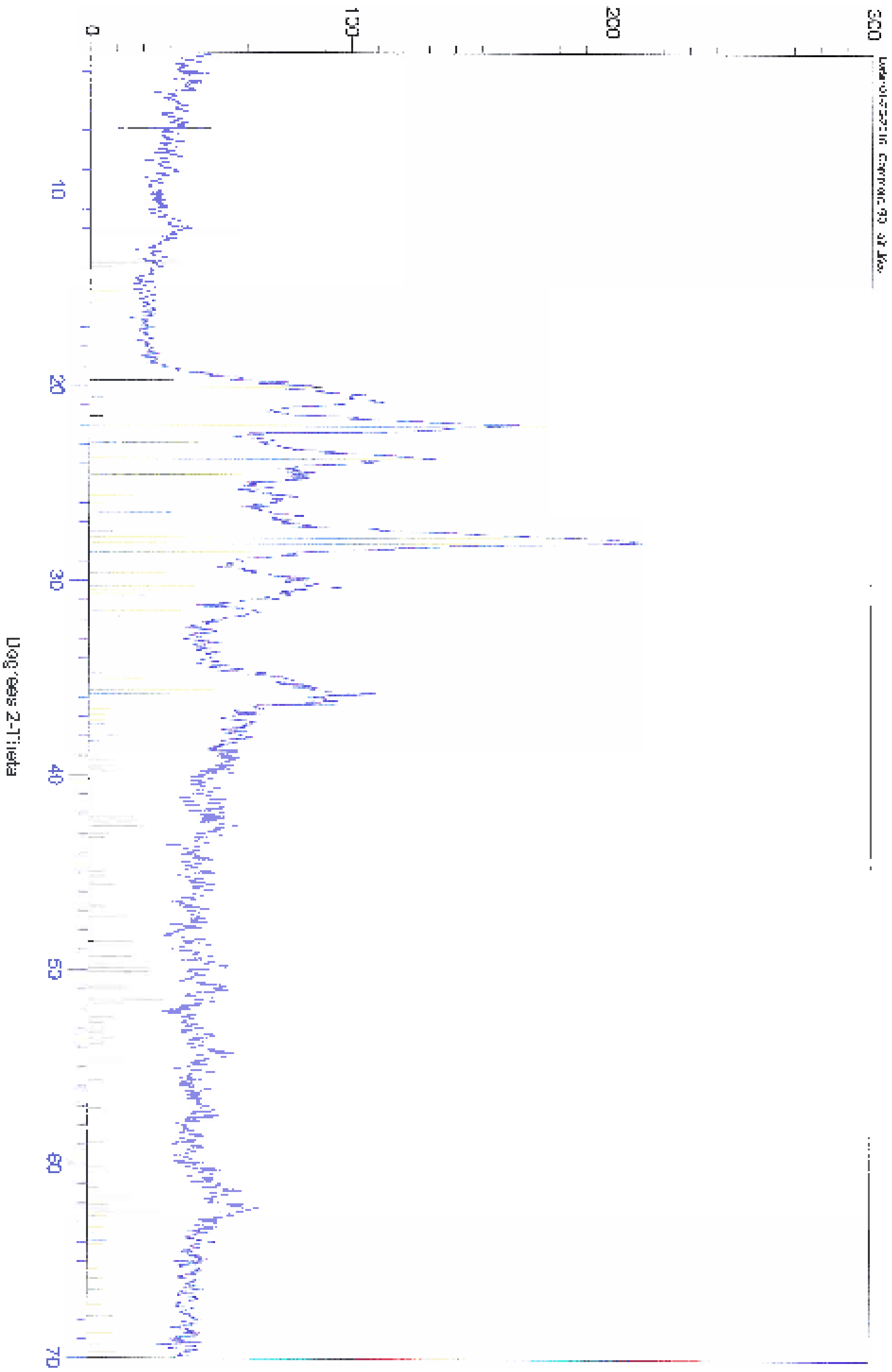
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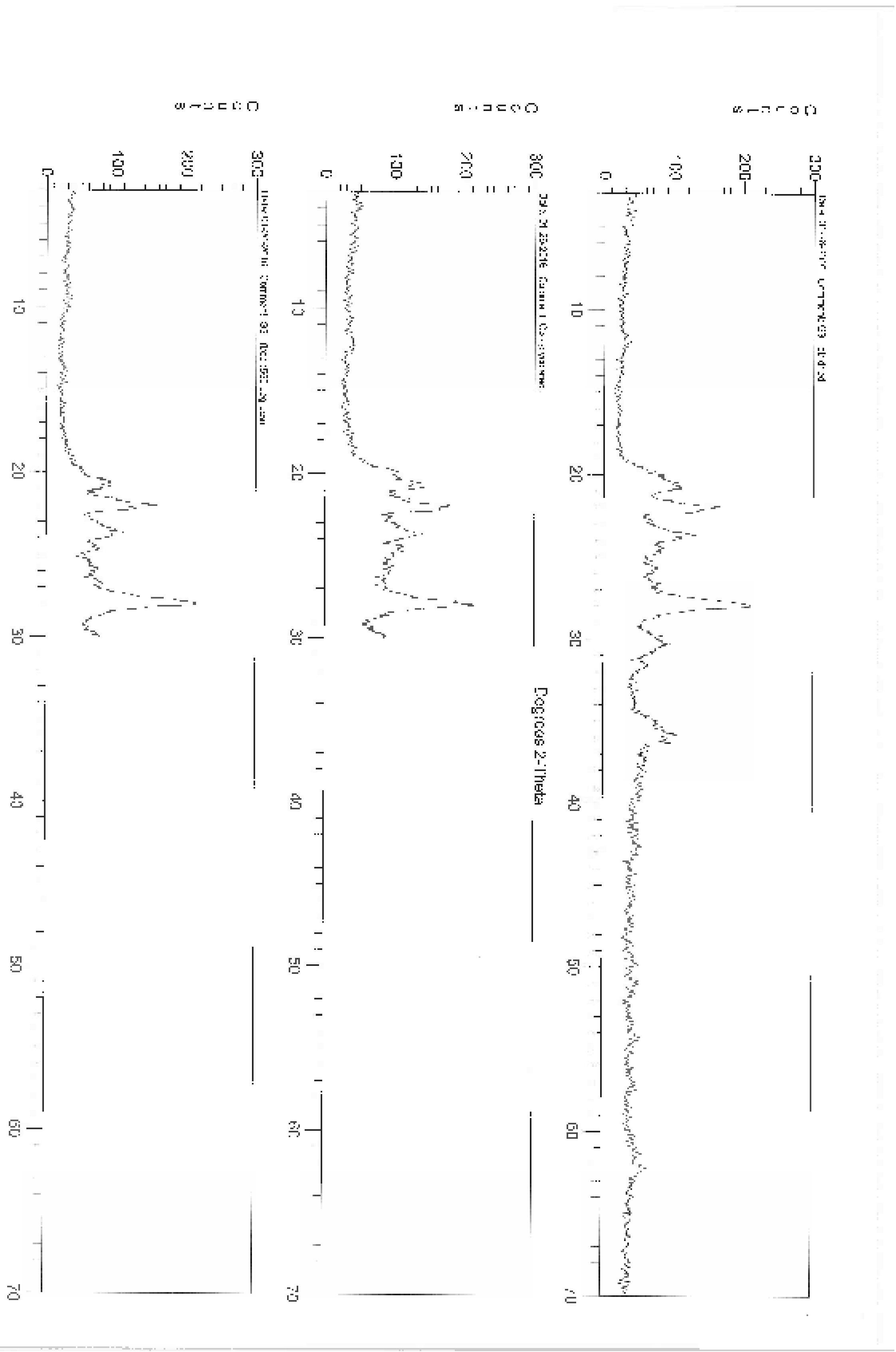
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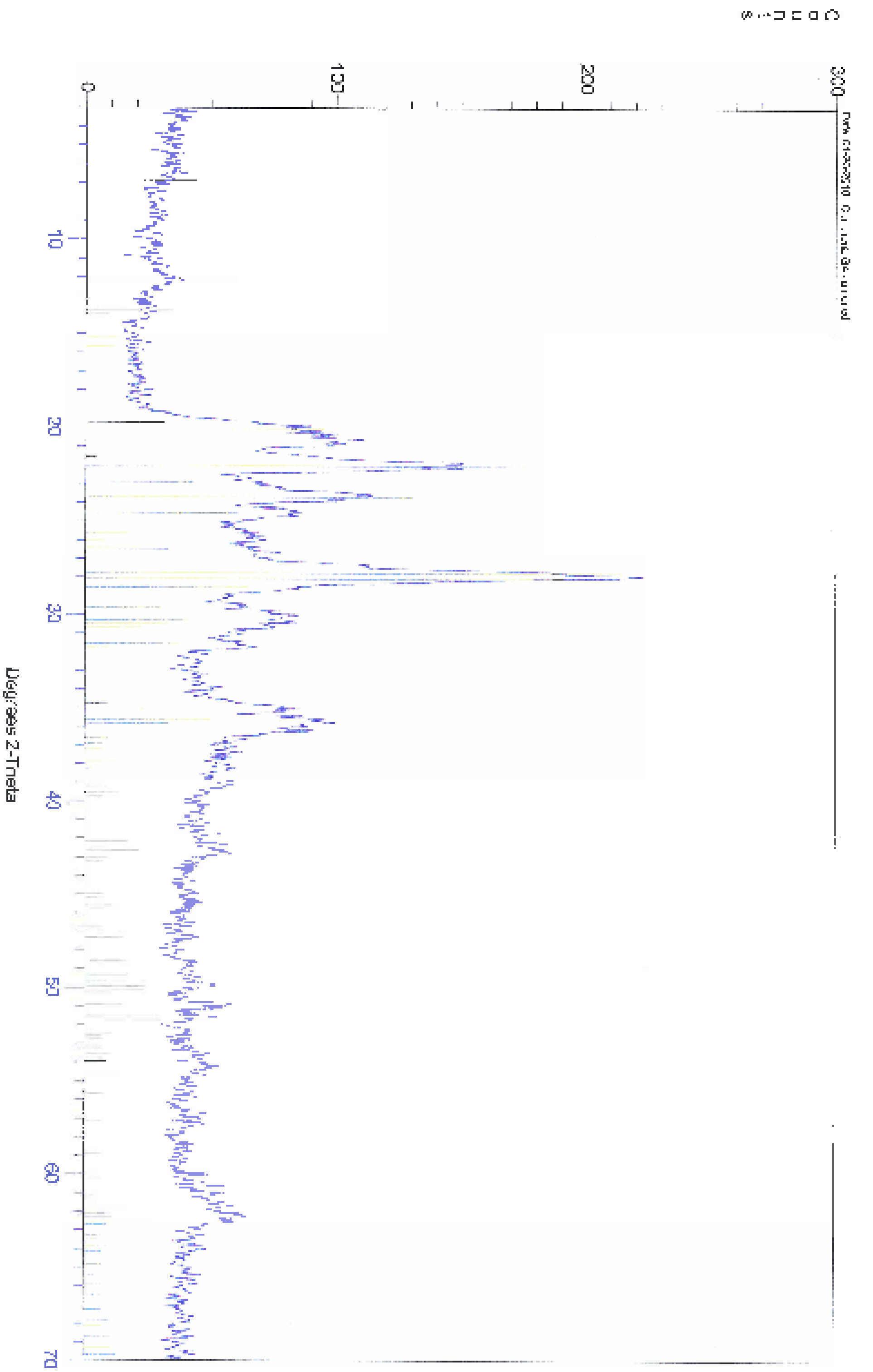
Counts
Counts
Degrees 2-Theta



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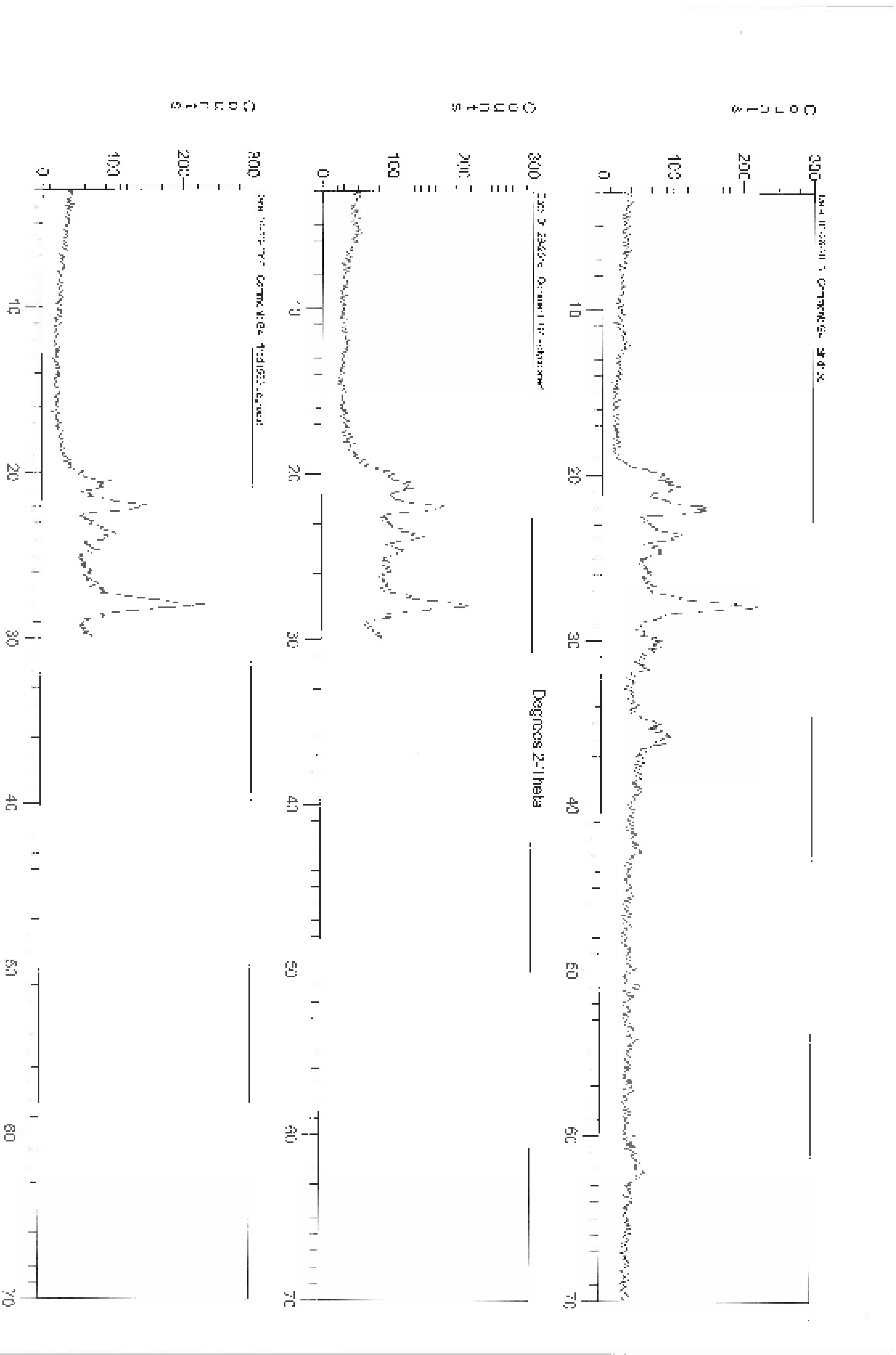
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Counts
Counts
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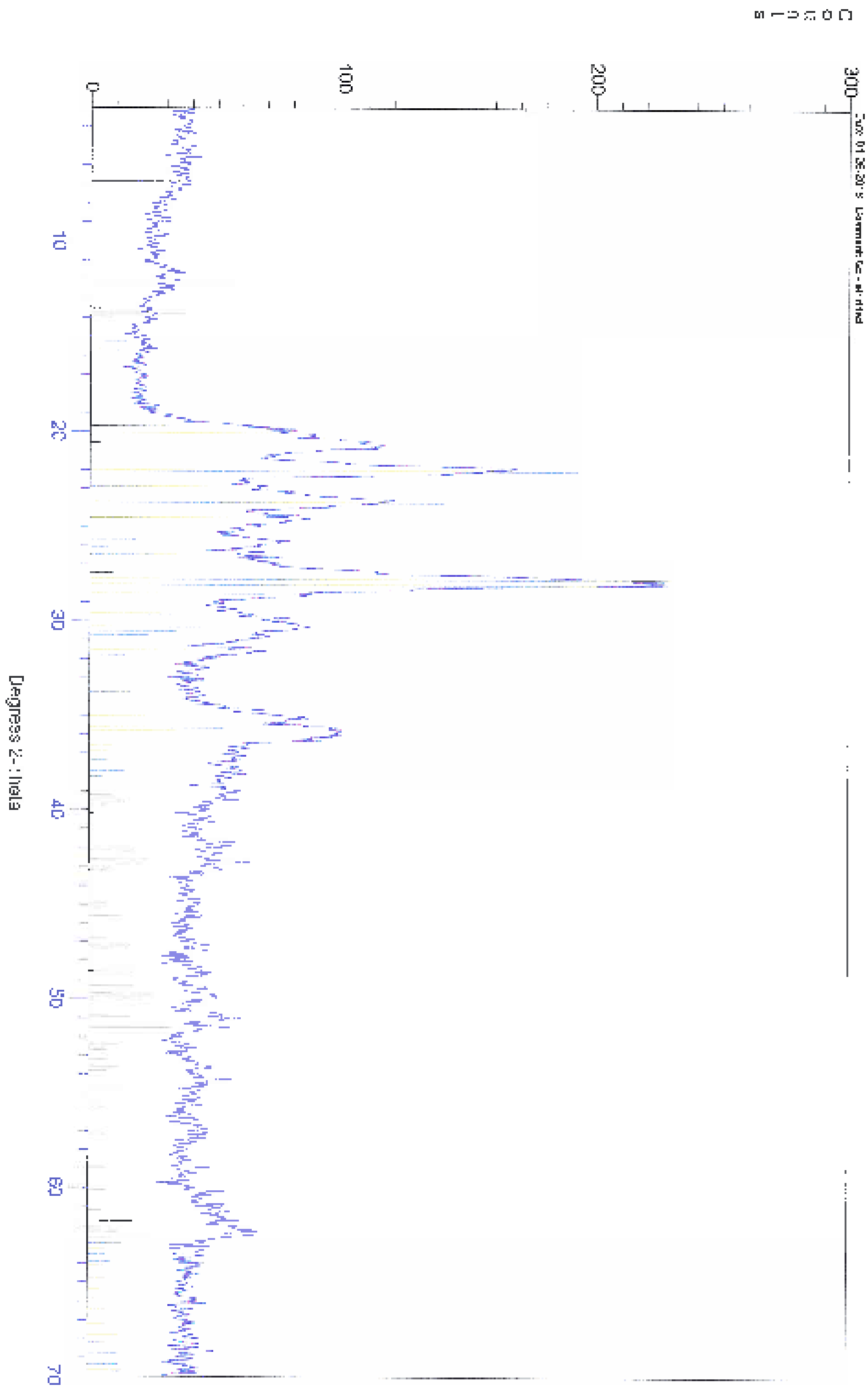

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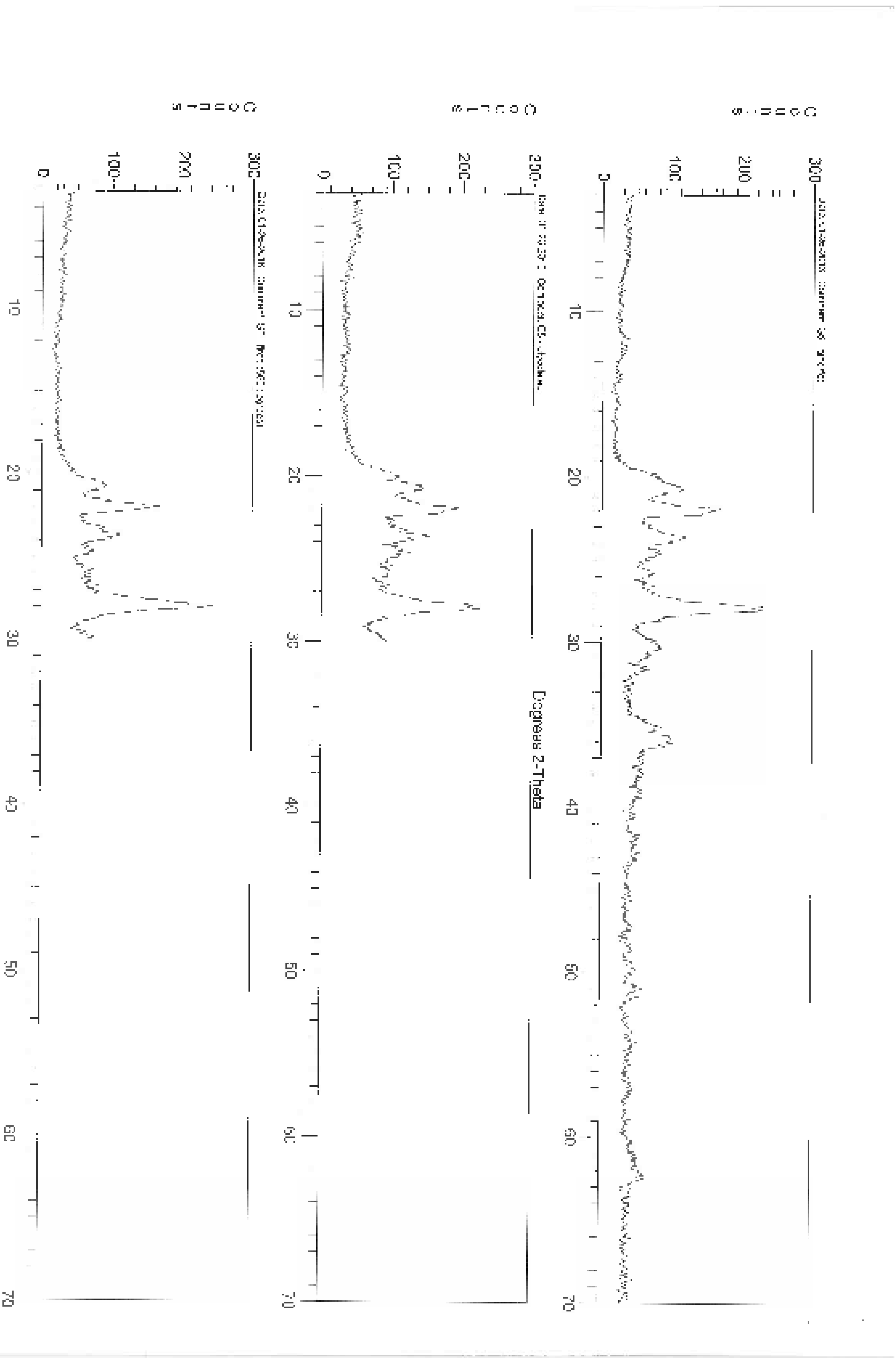
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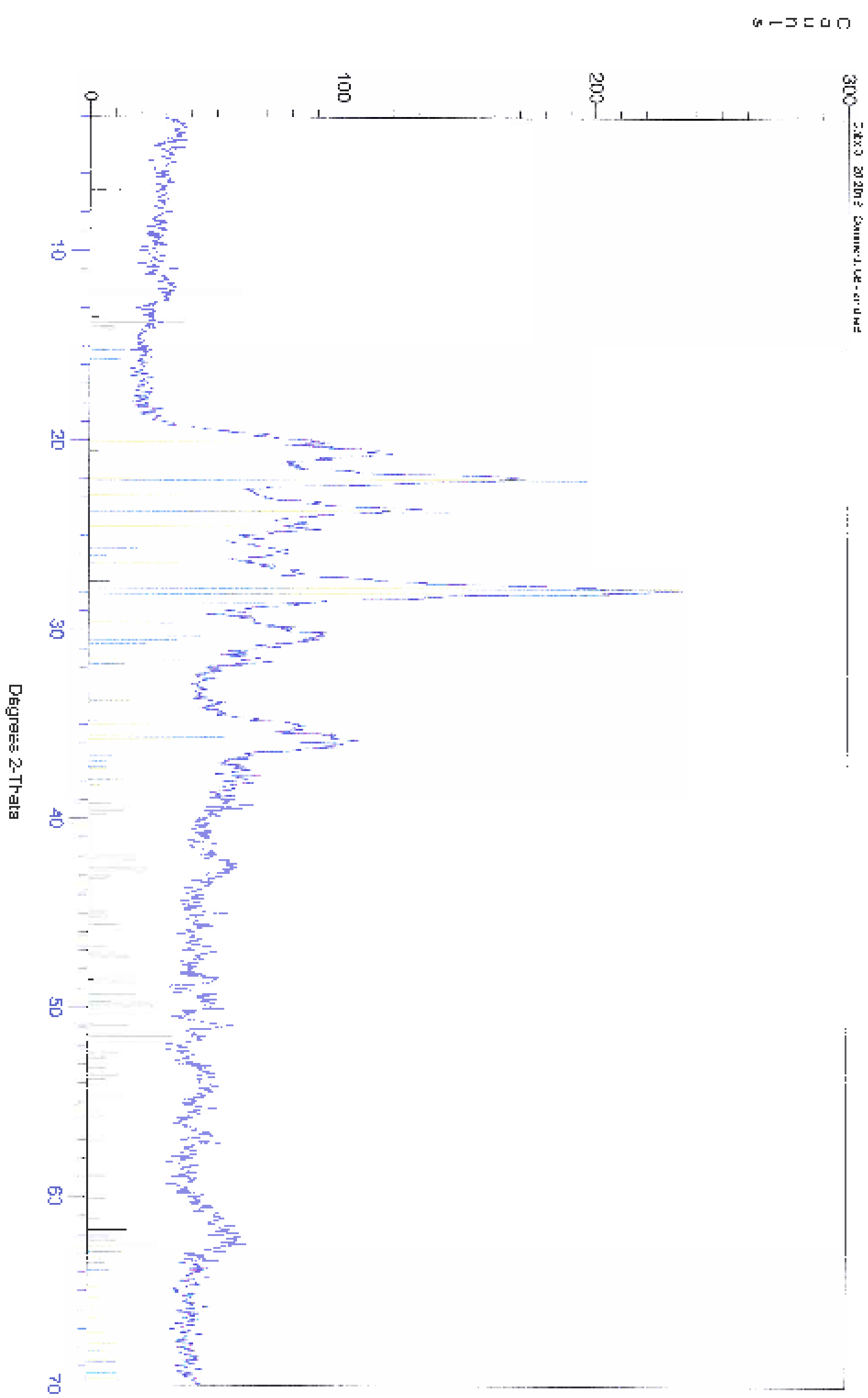

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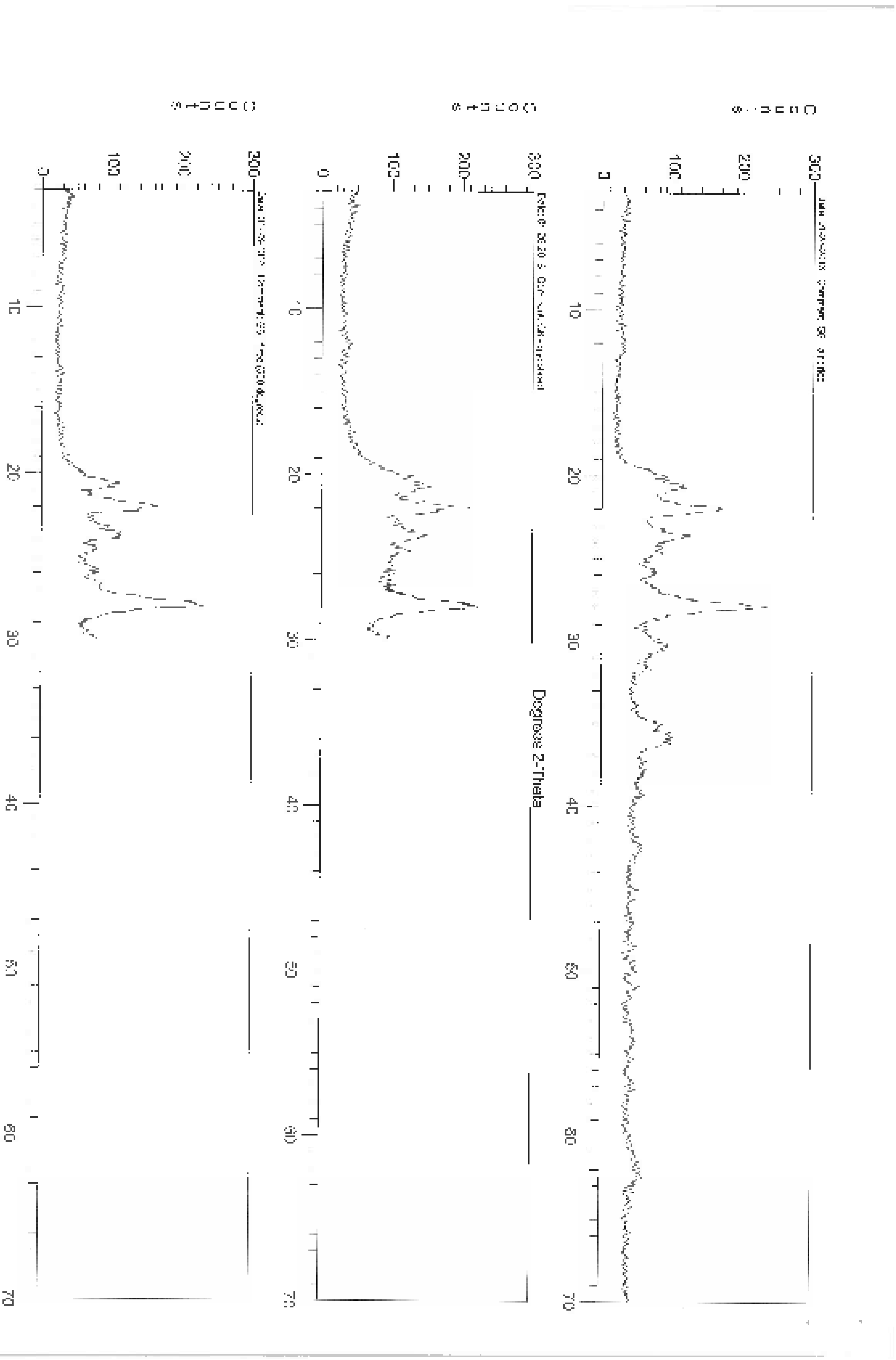
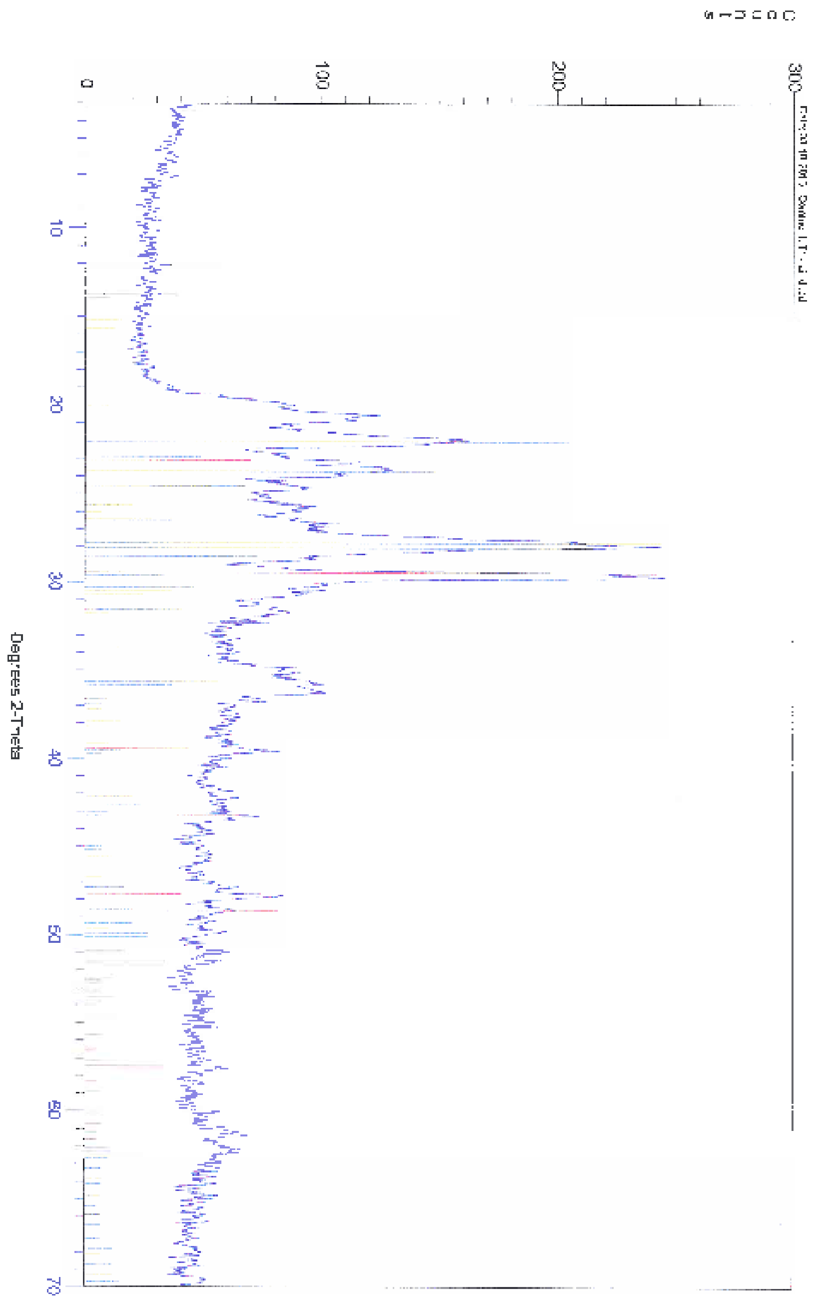
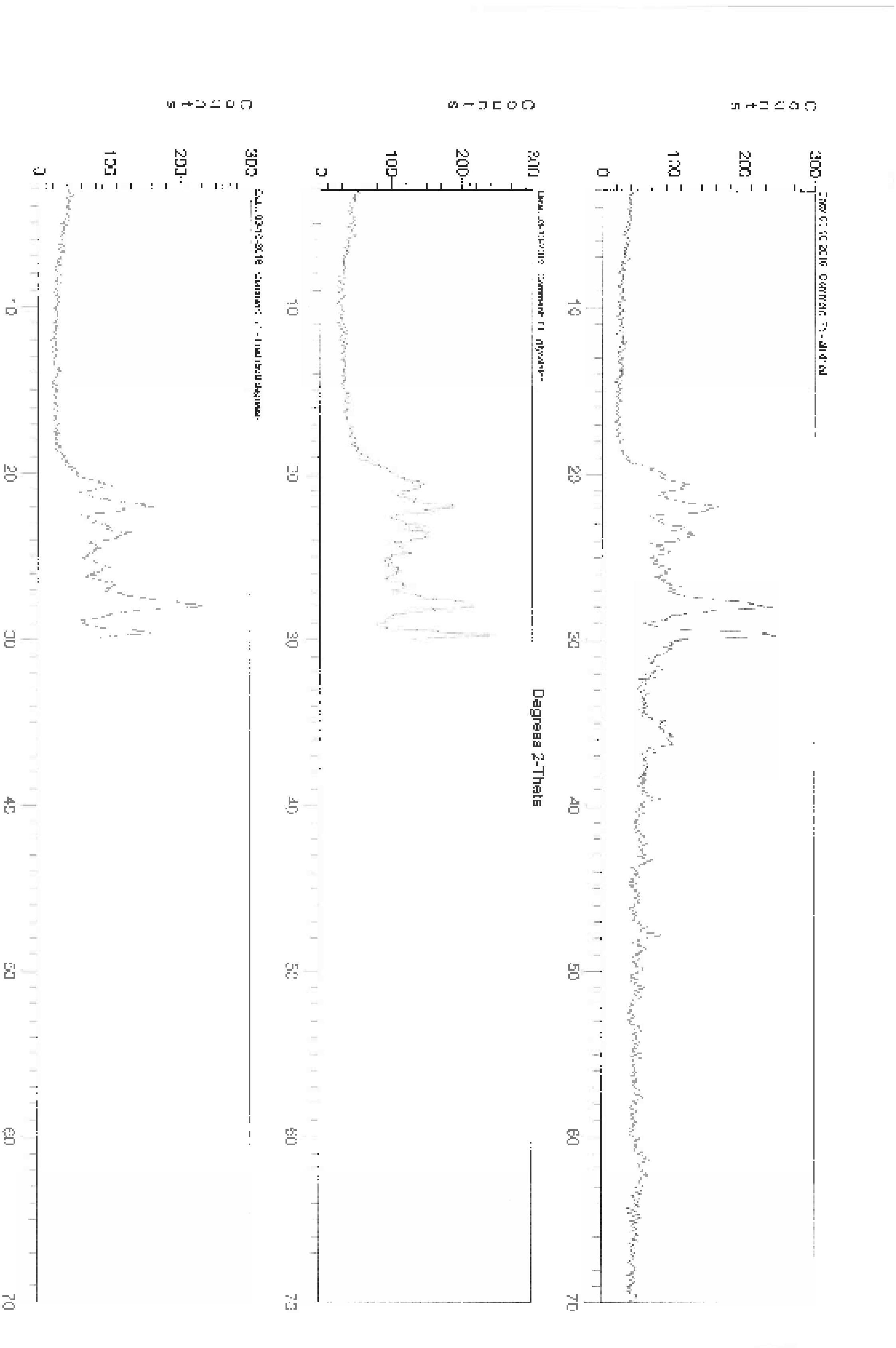

Degrees 2-Theta

L.2T-Grade XRD Spectrums

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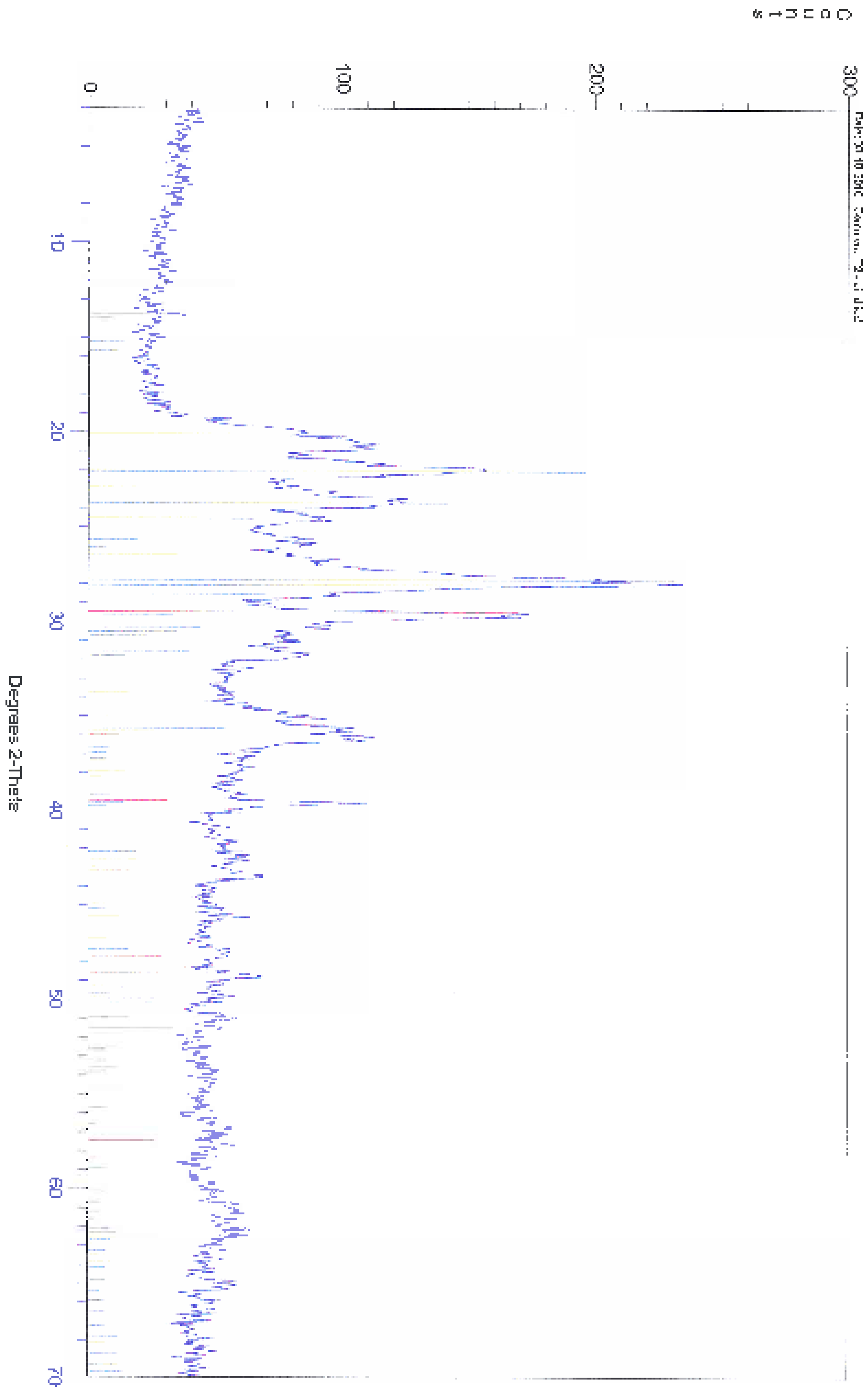
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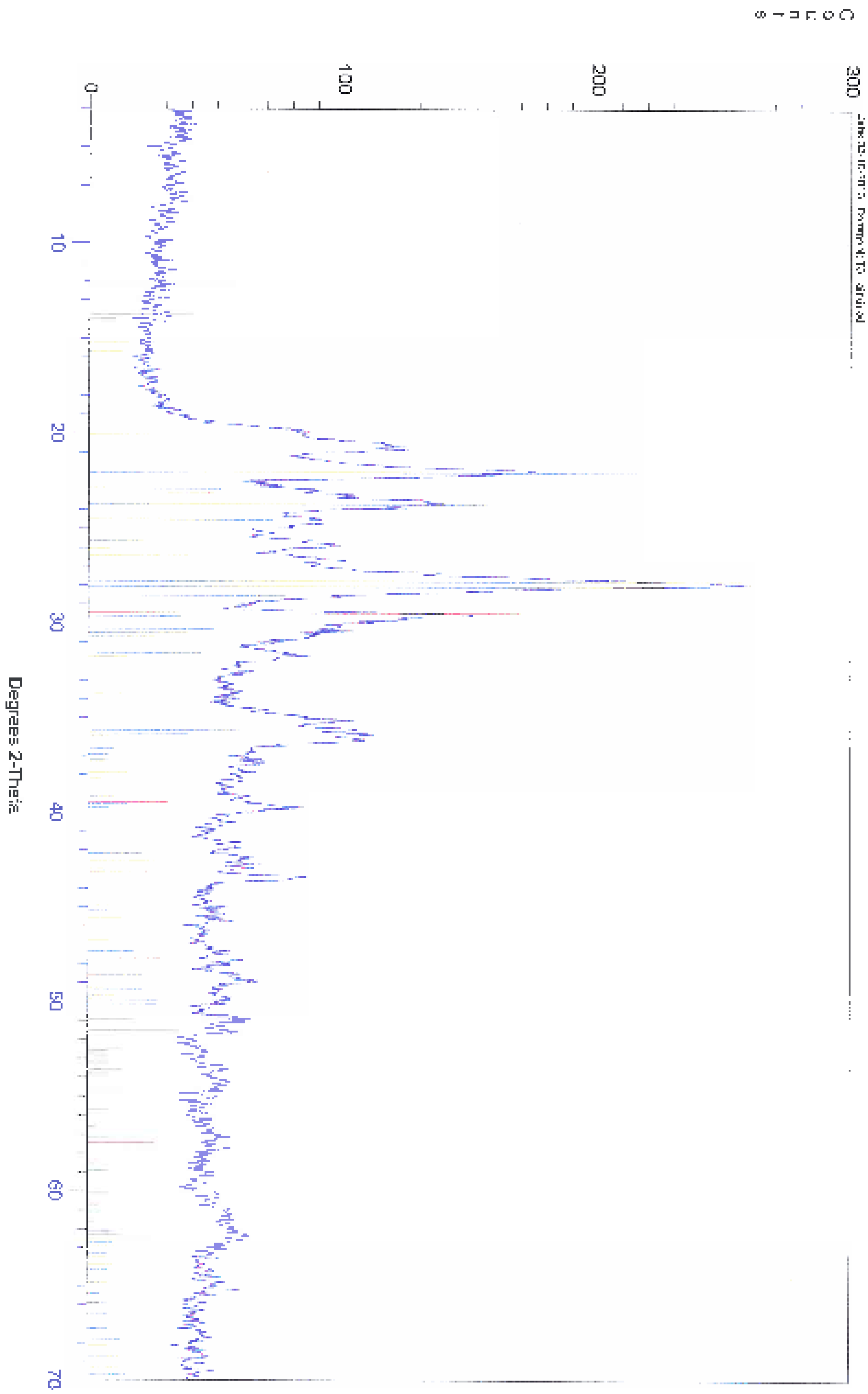
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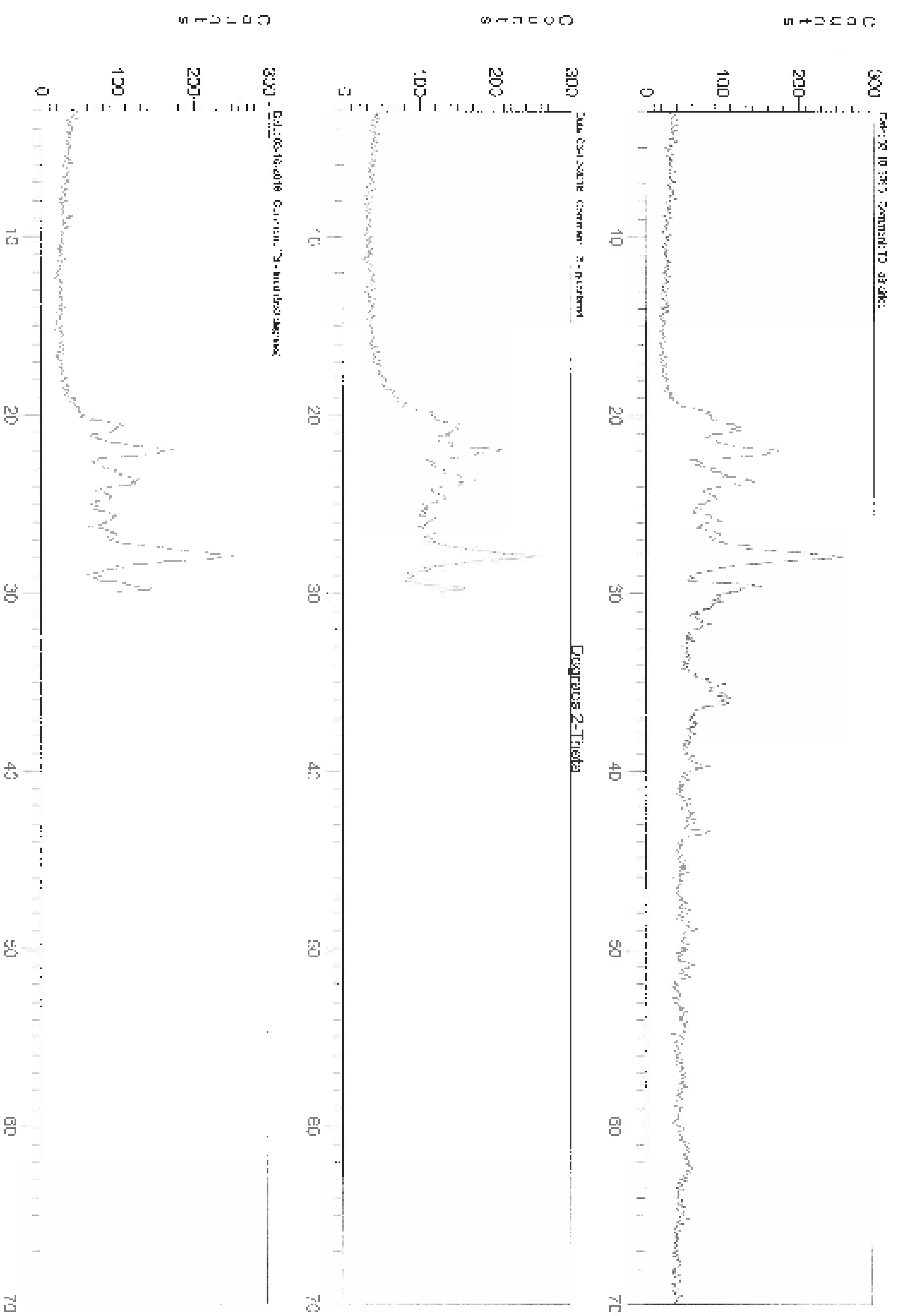
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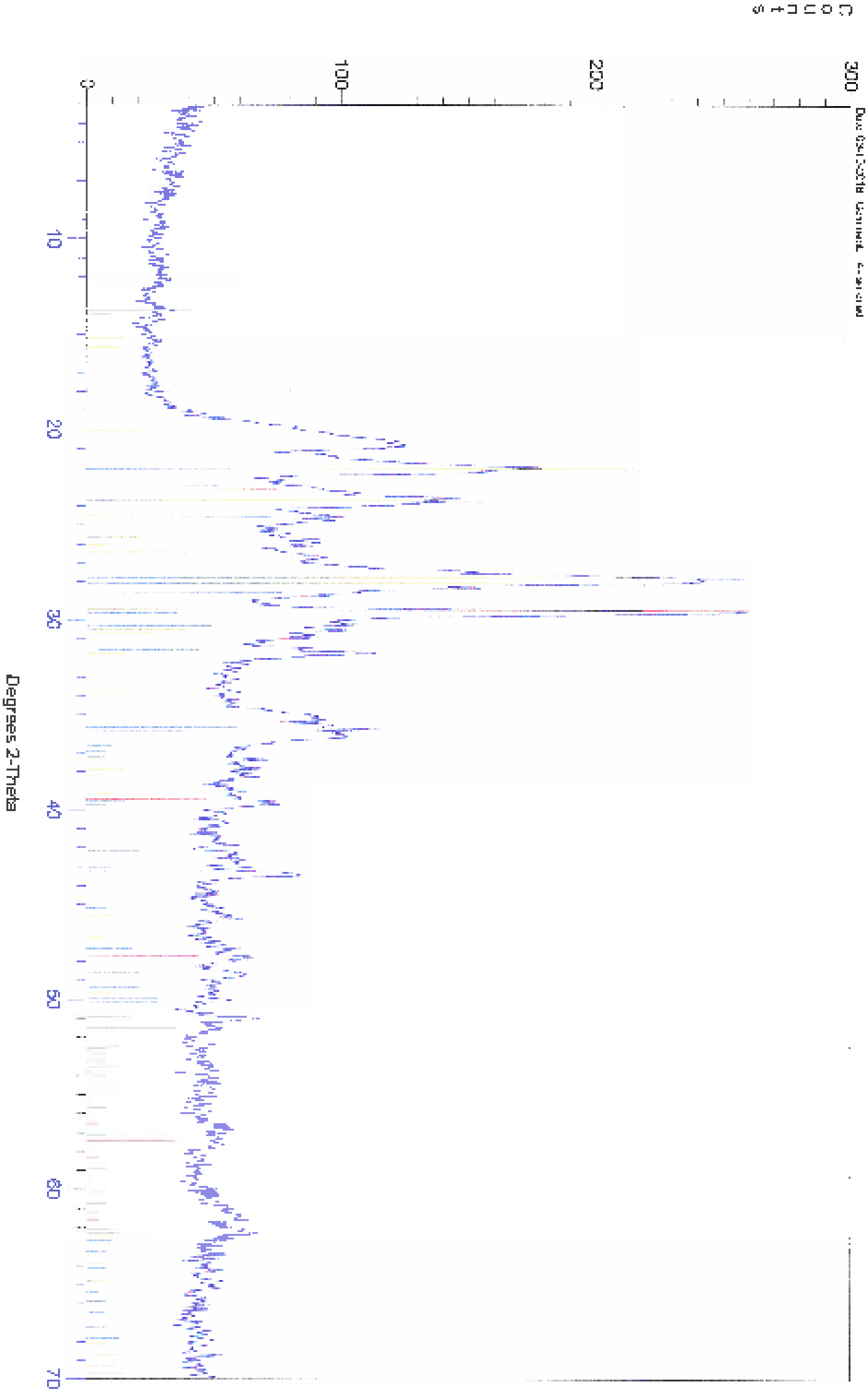
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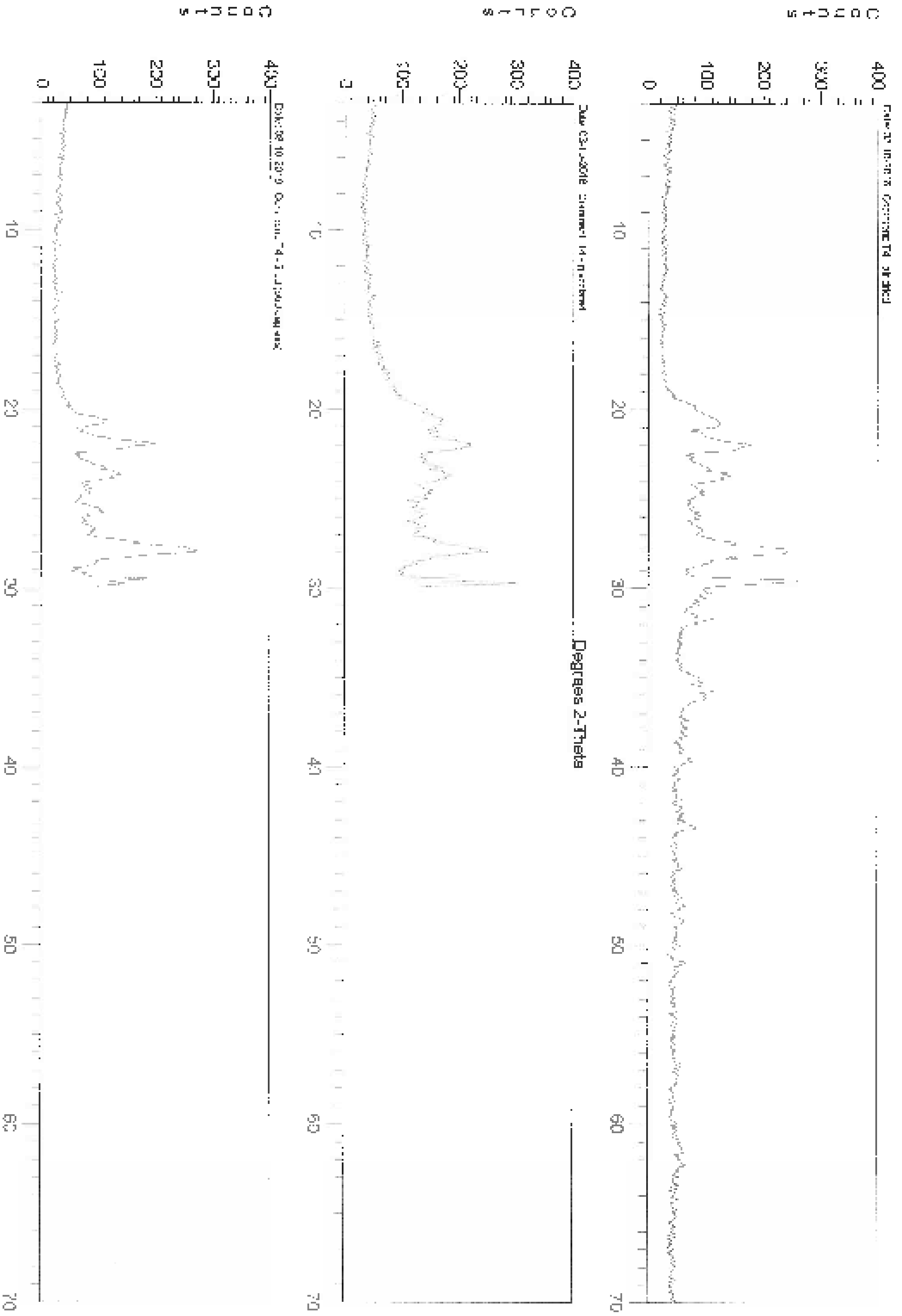
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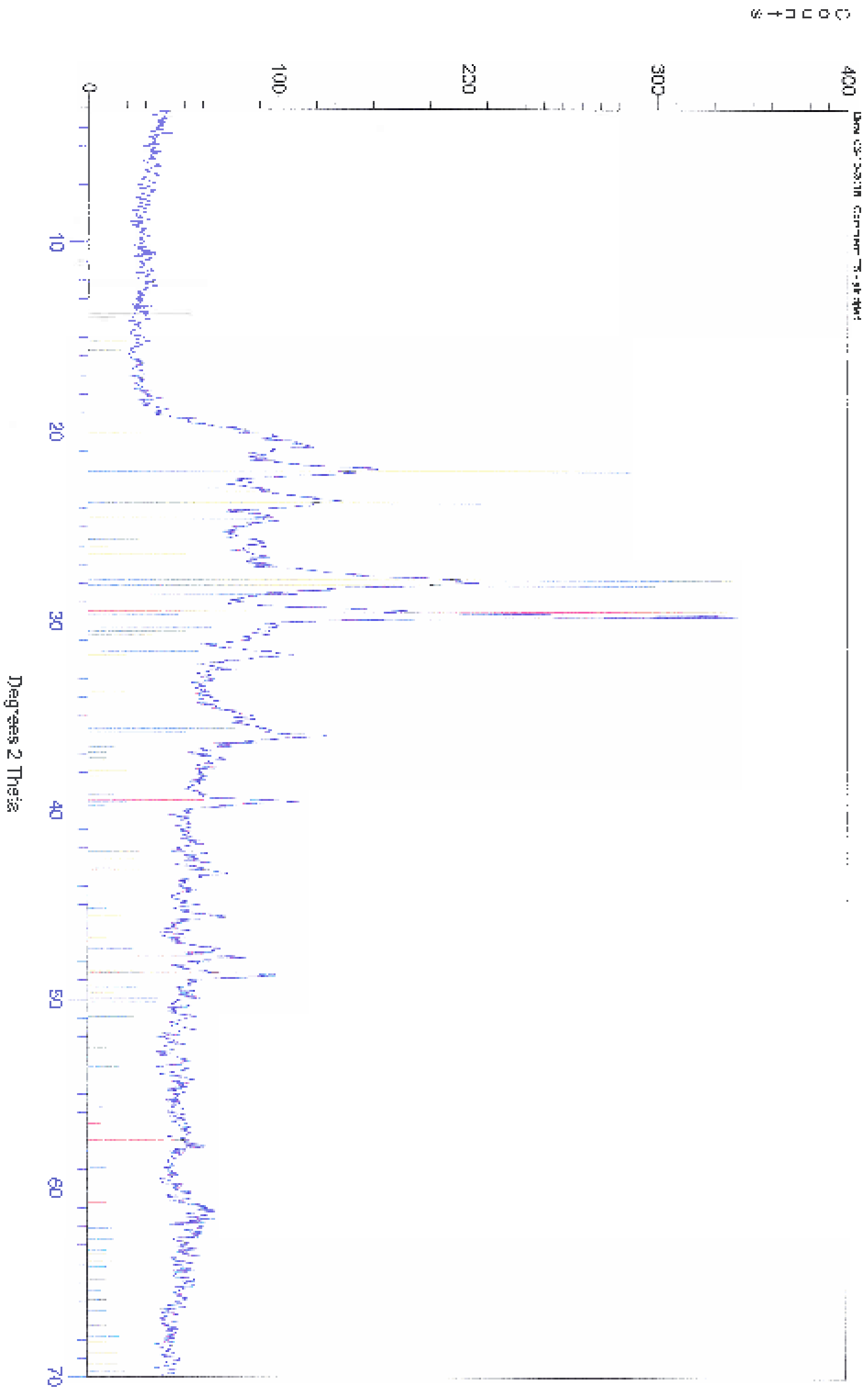
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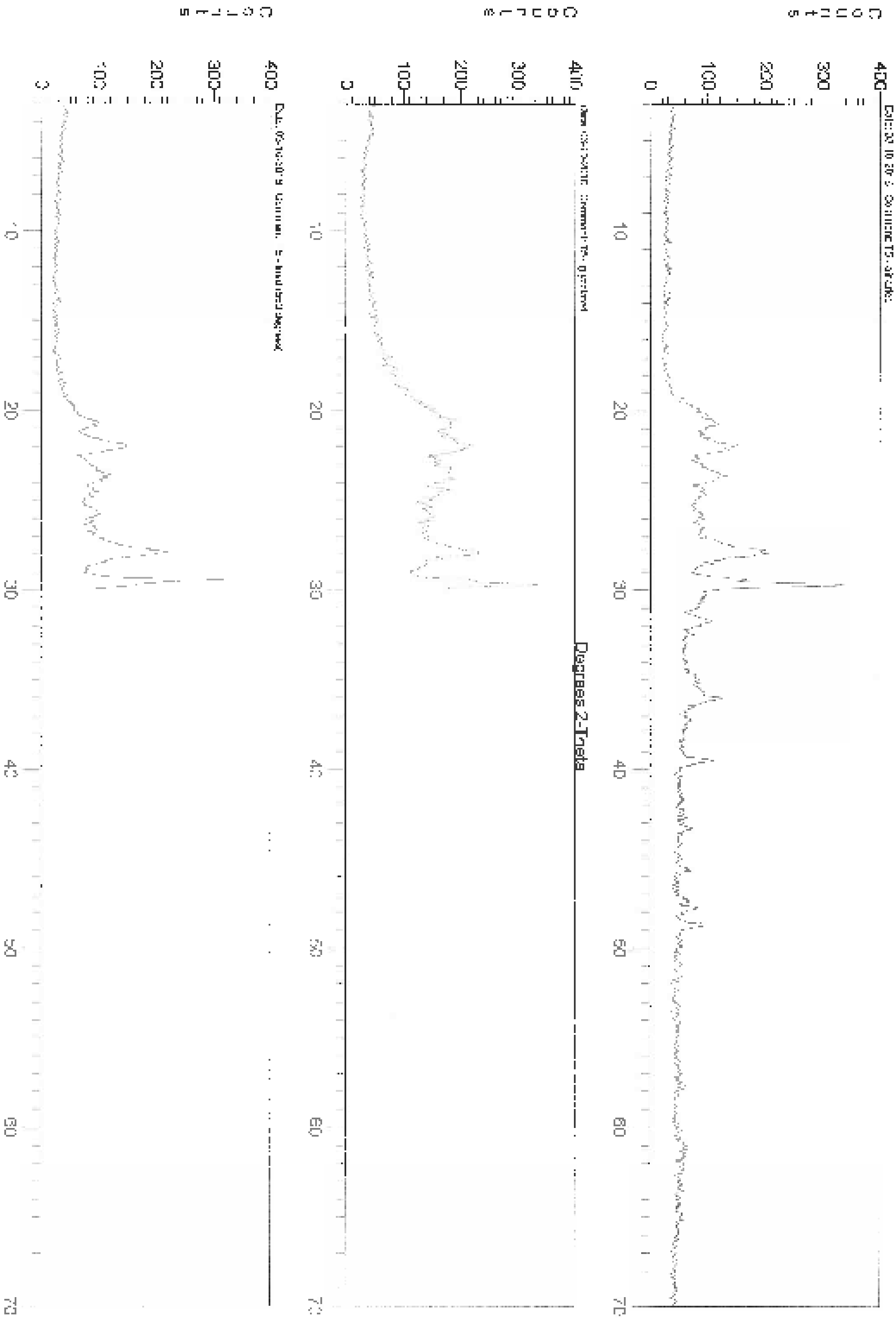
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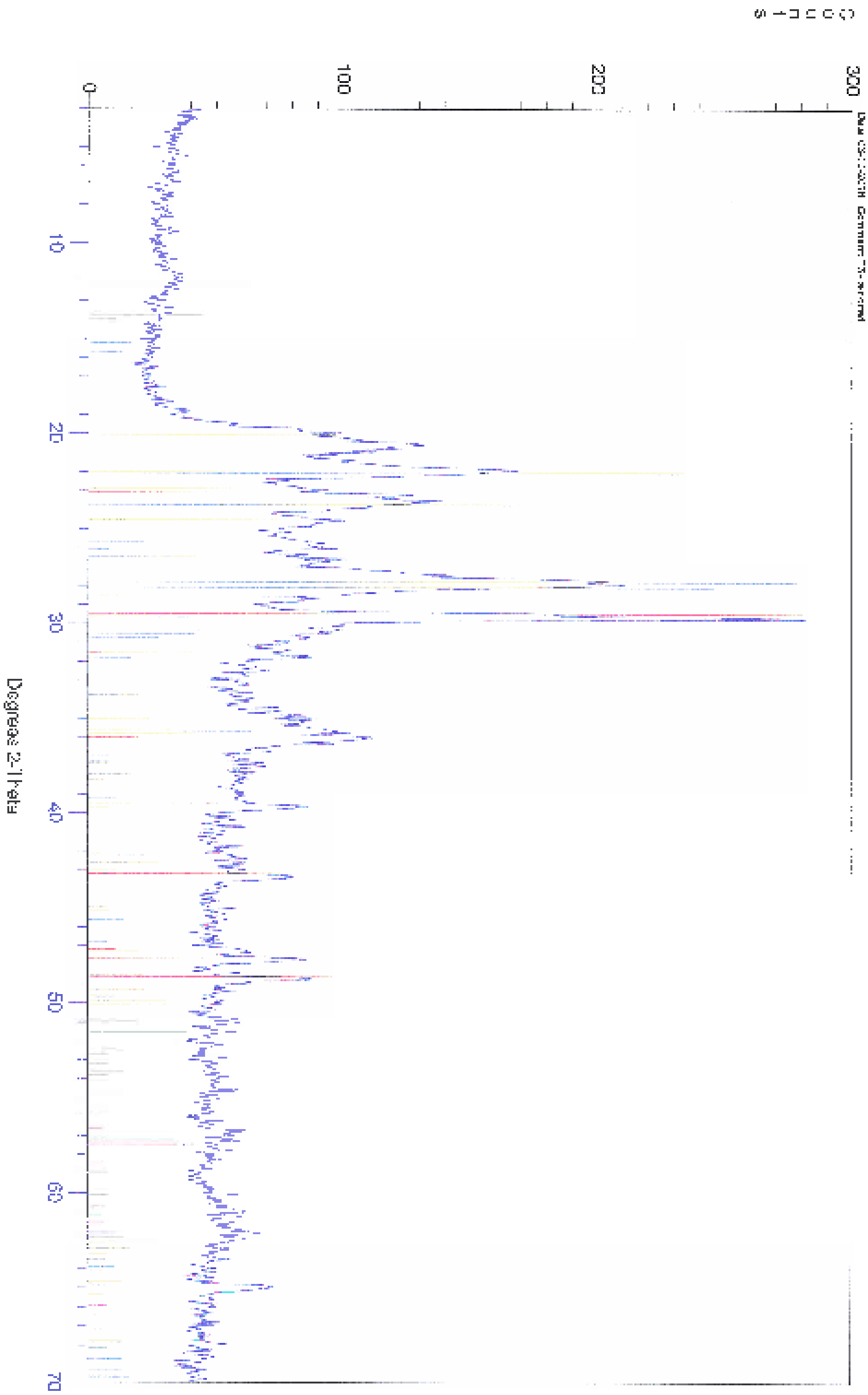
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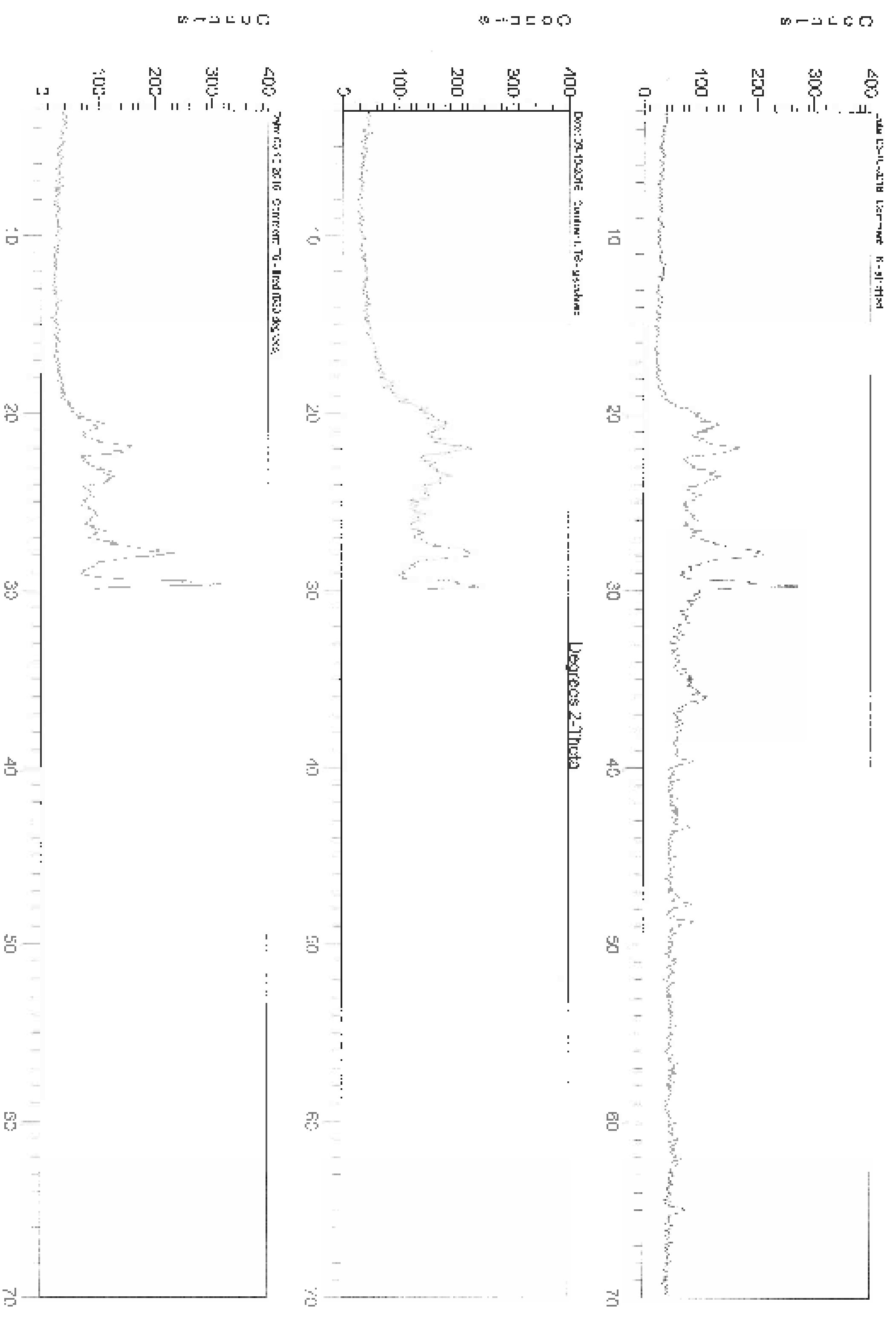
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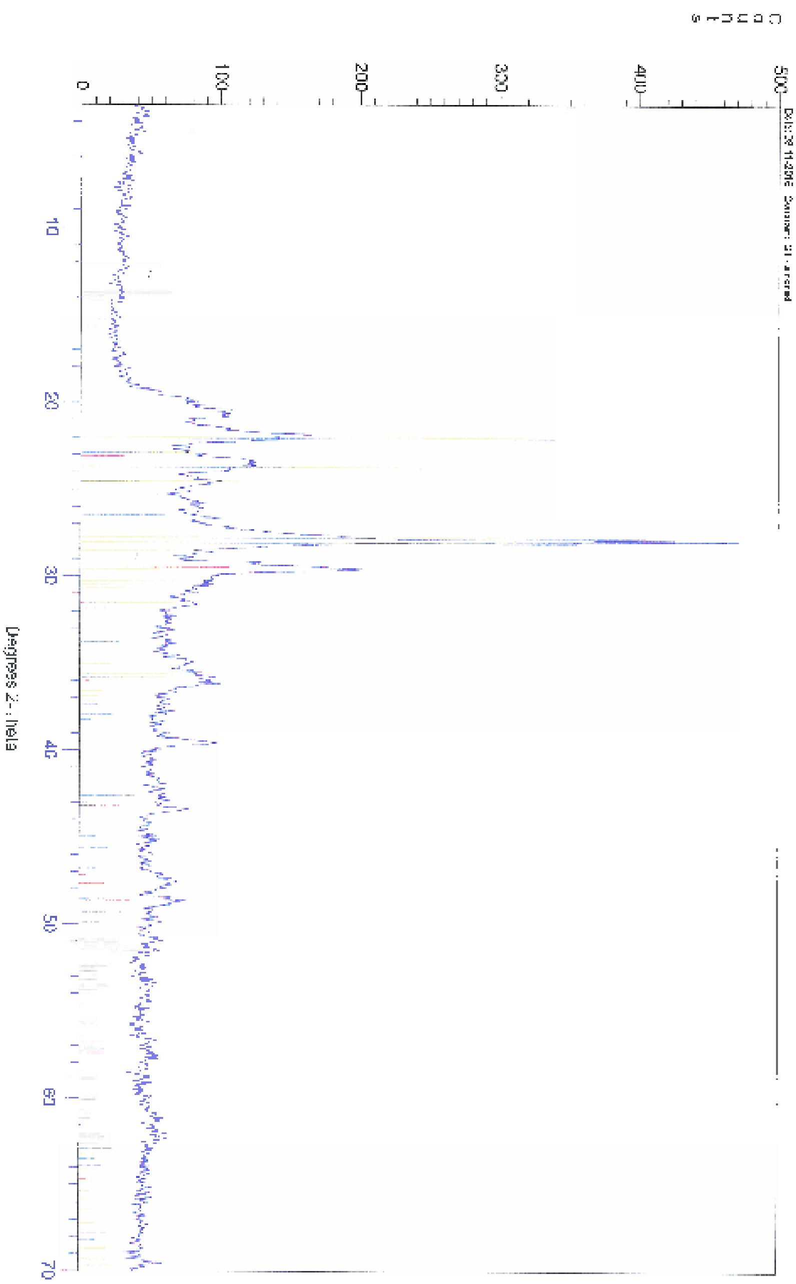
L.3C- Grade XRD Spectrums

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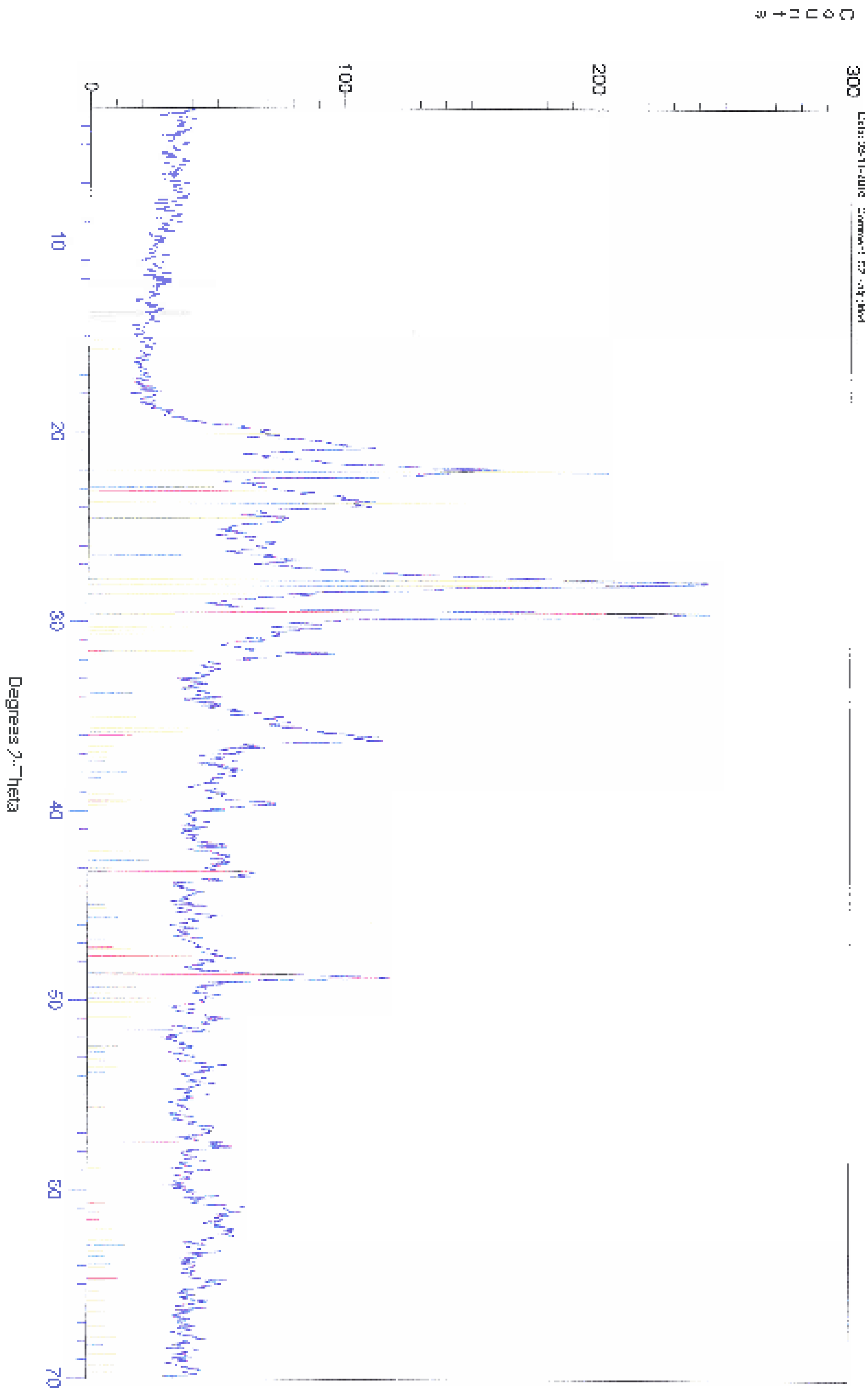
Counts
Counts
Degrees 2 Theta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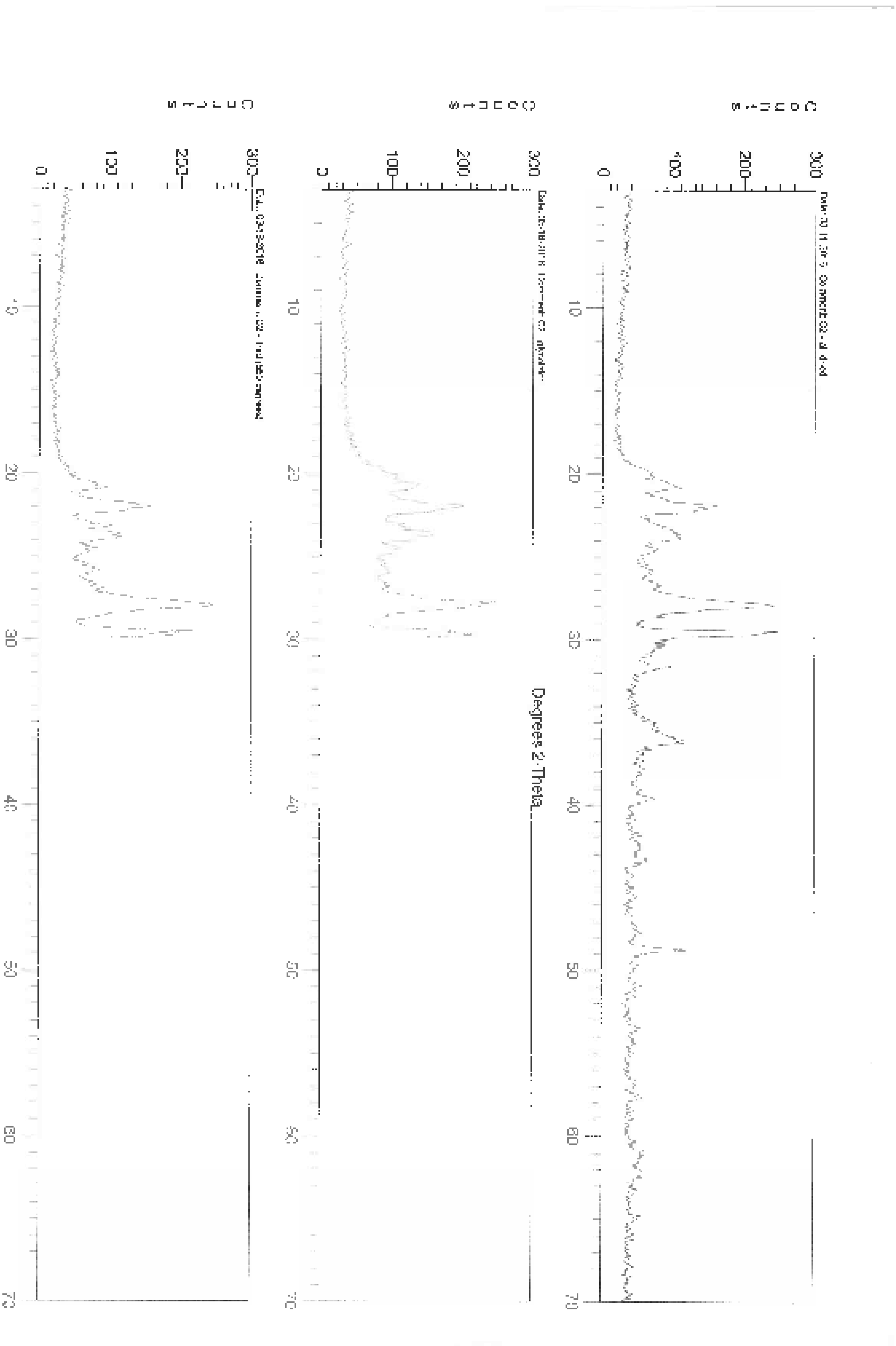
Degrees 2-Theta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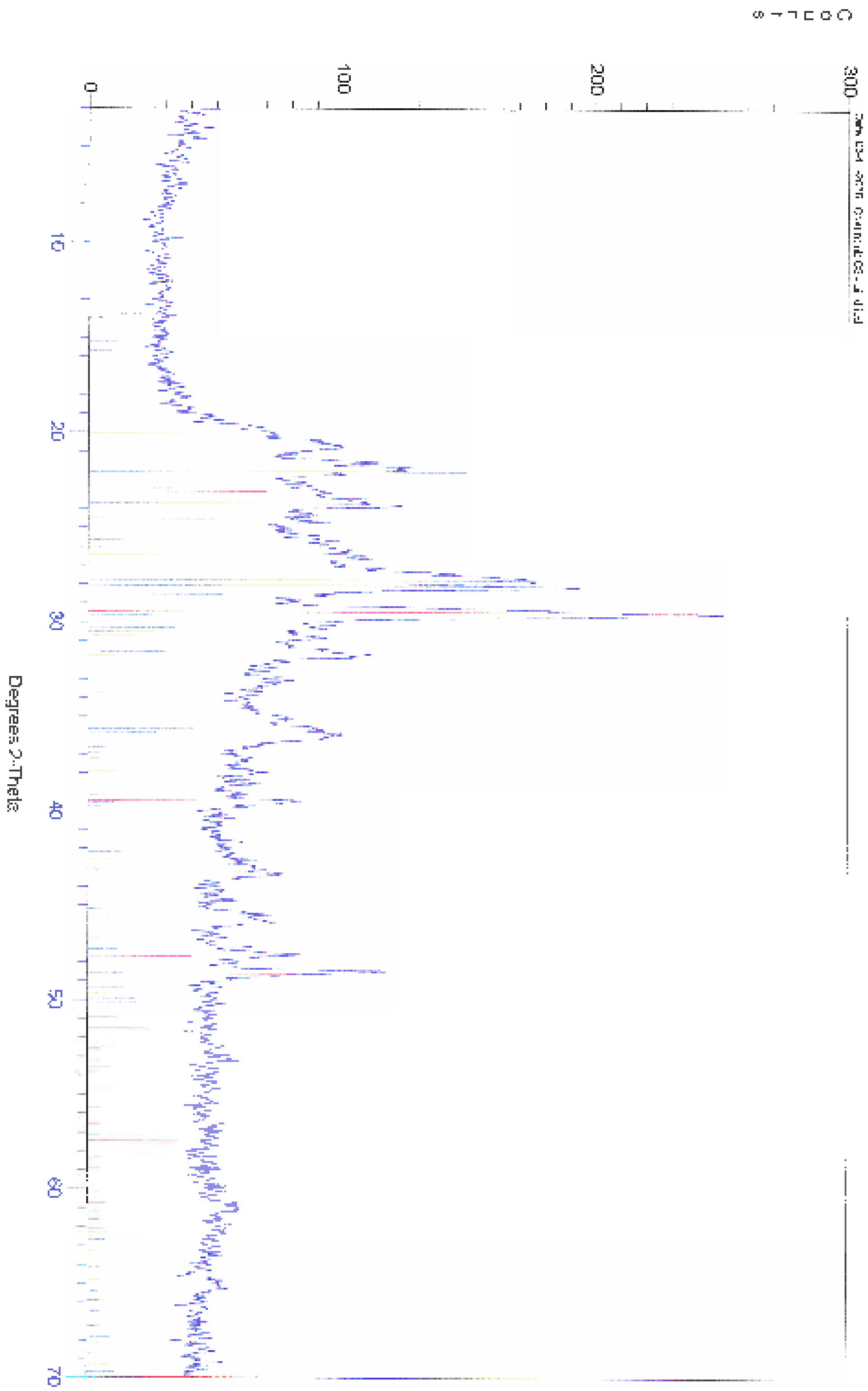
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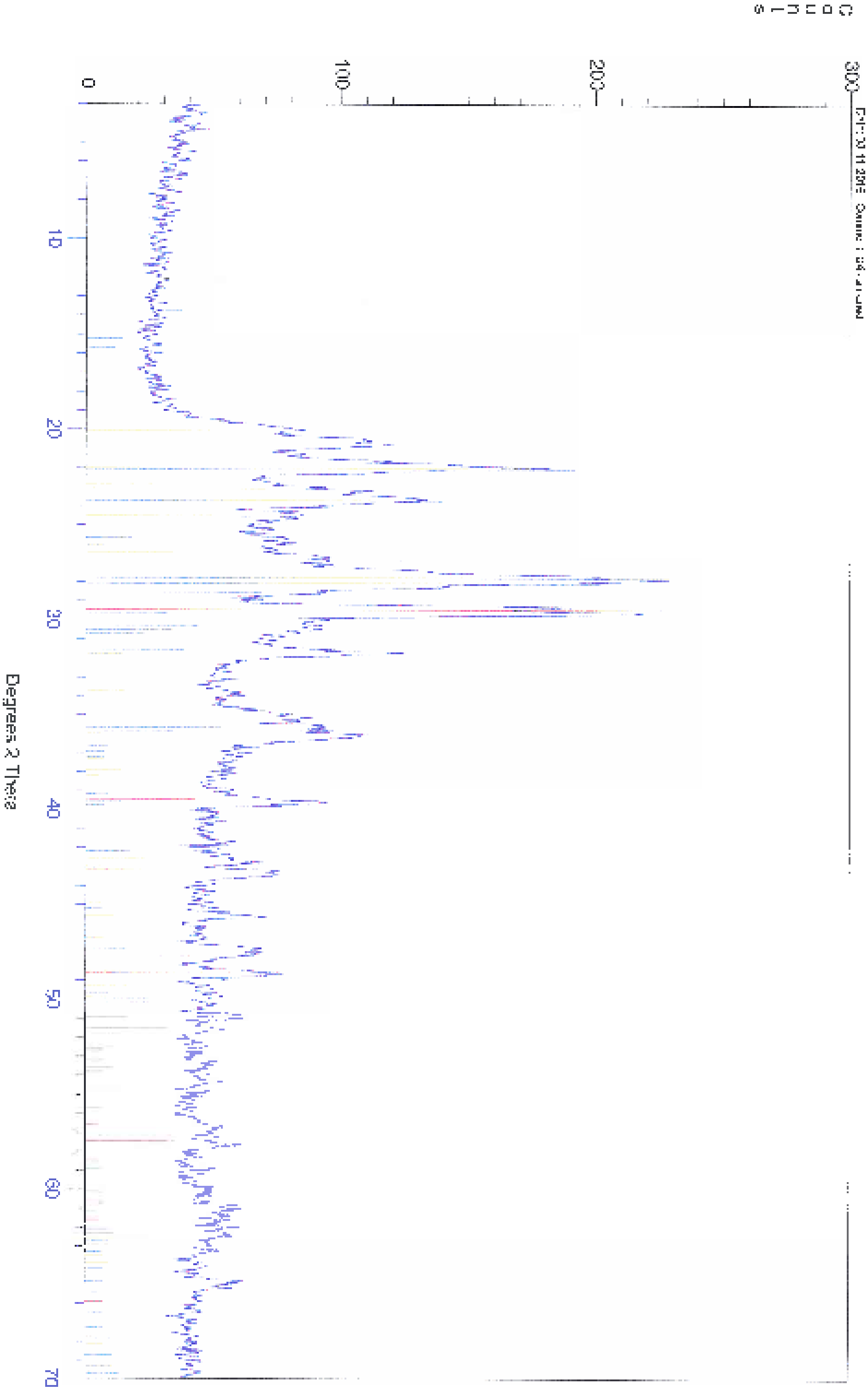
Degrees 2-Theta


Counts
Degrees 2 Theta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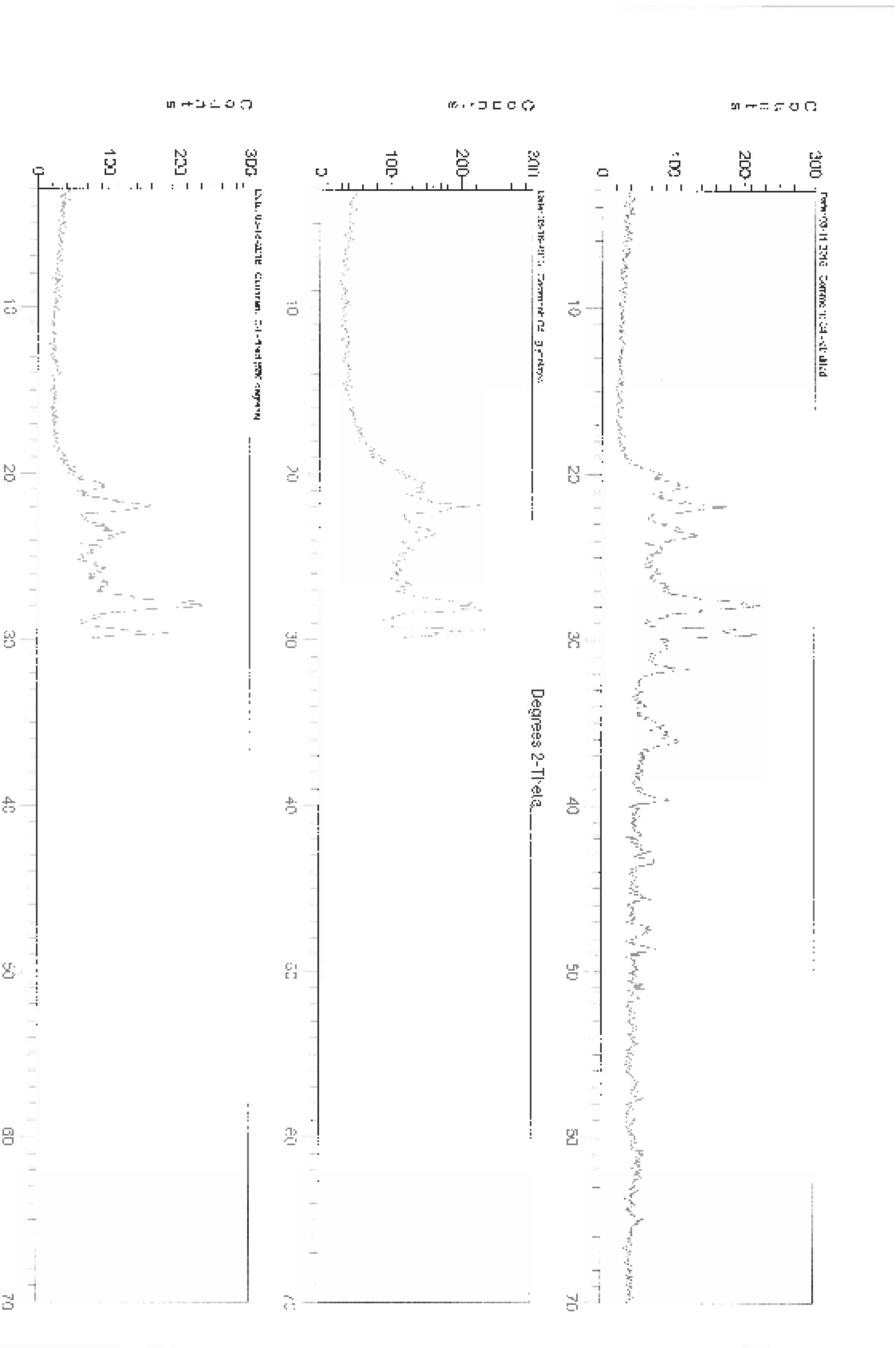
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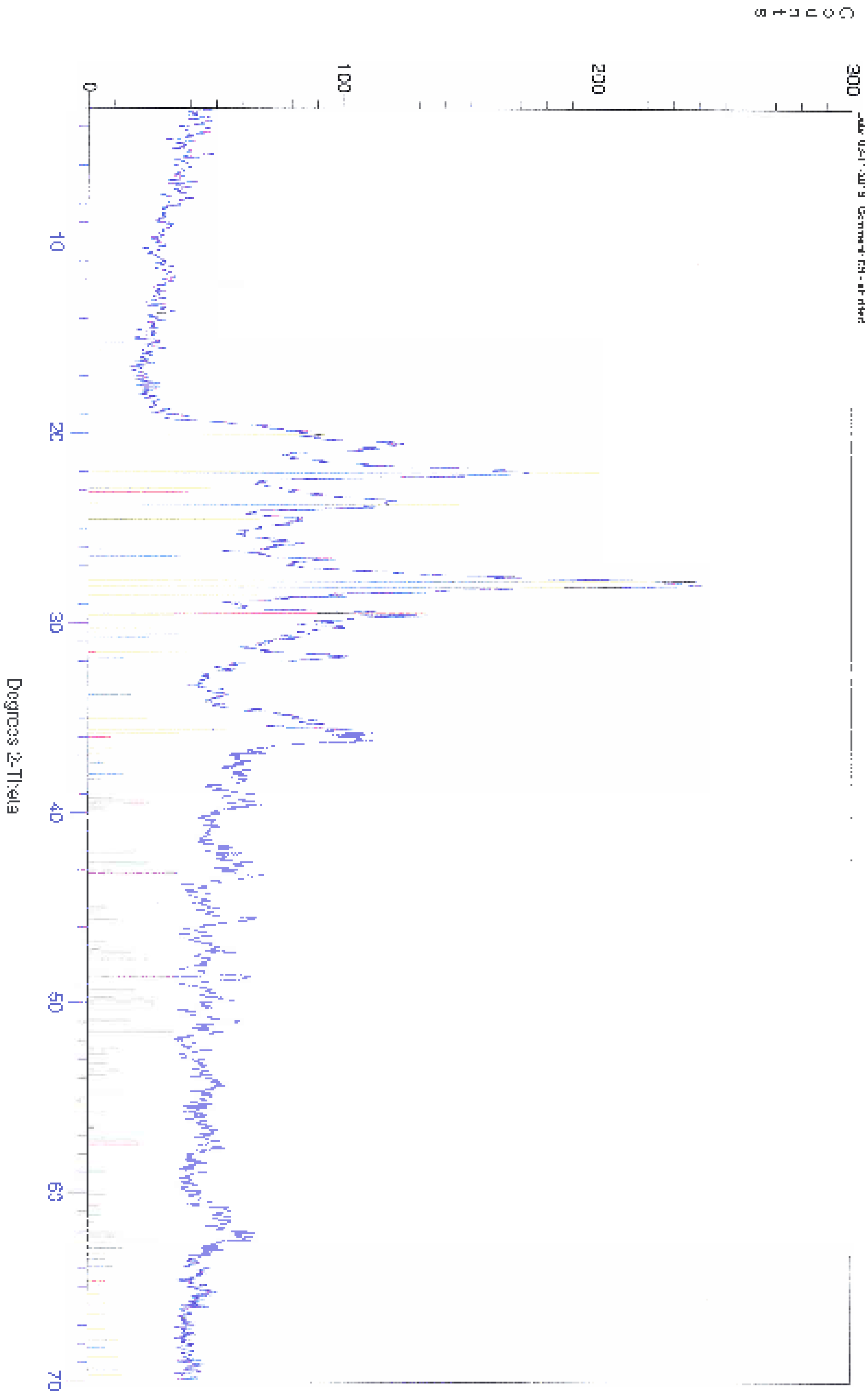
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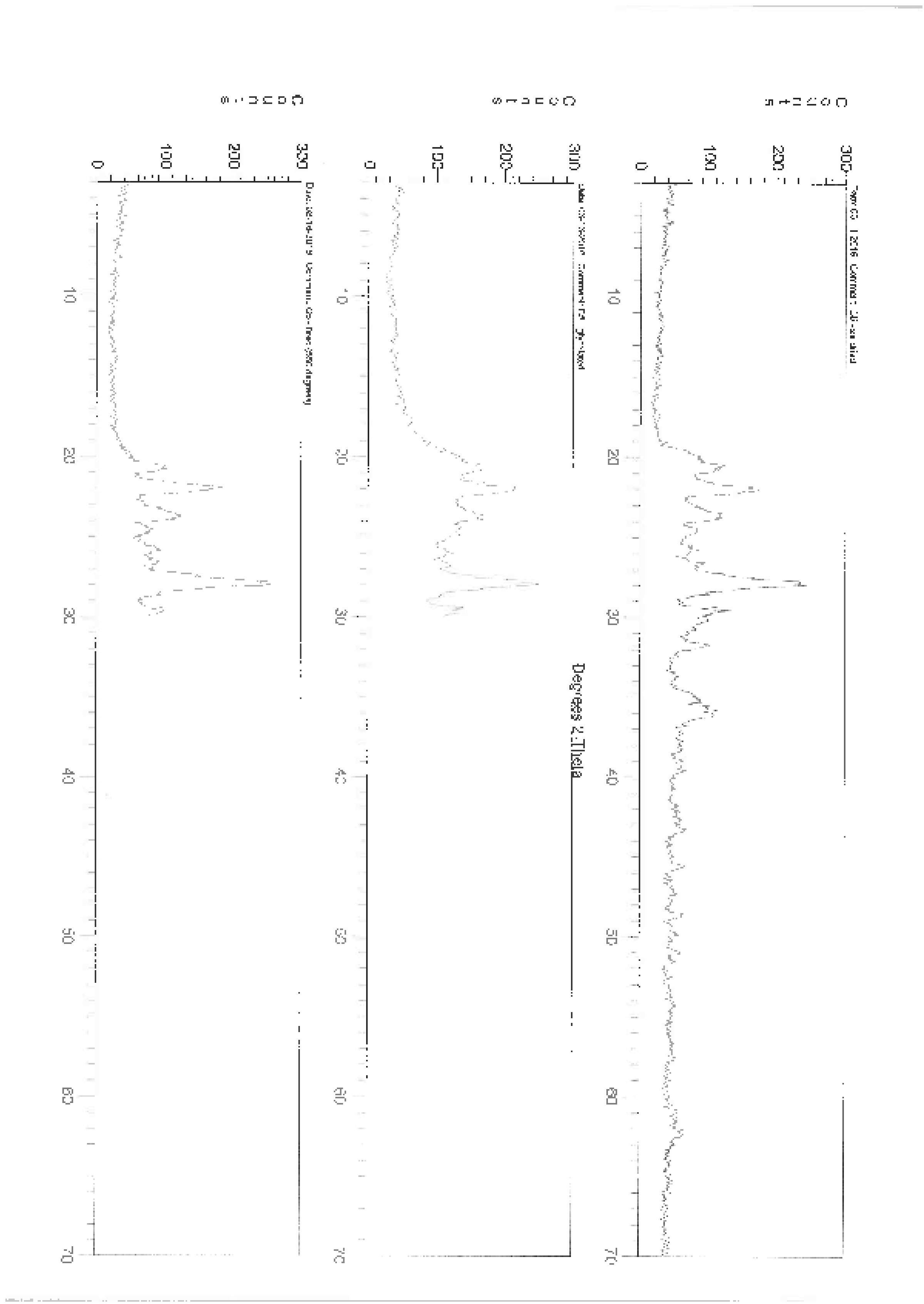
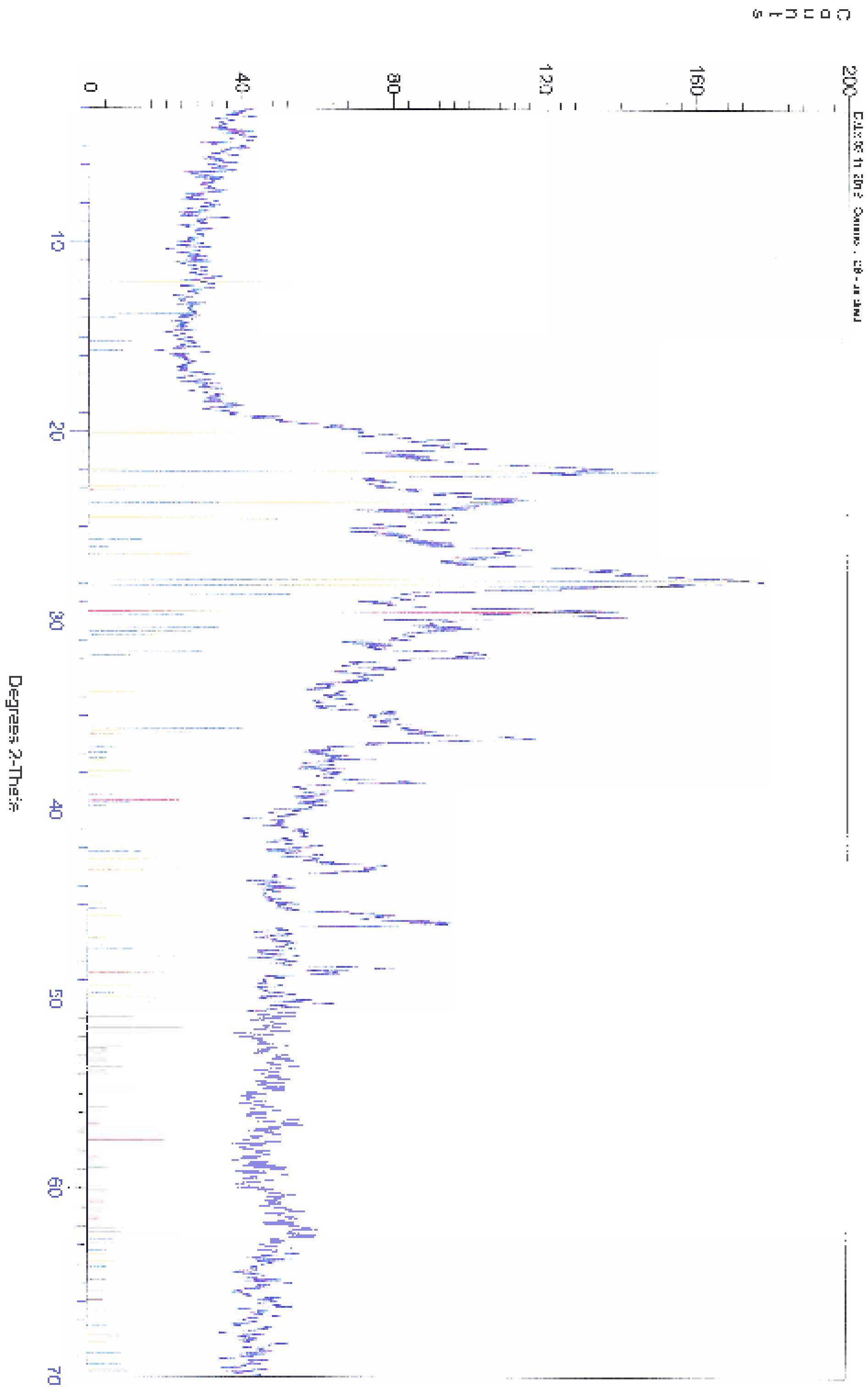
Degrees 2-Theta


Degrees 2 Theta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200
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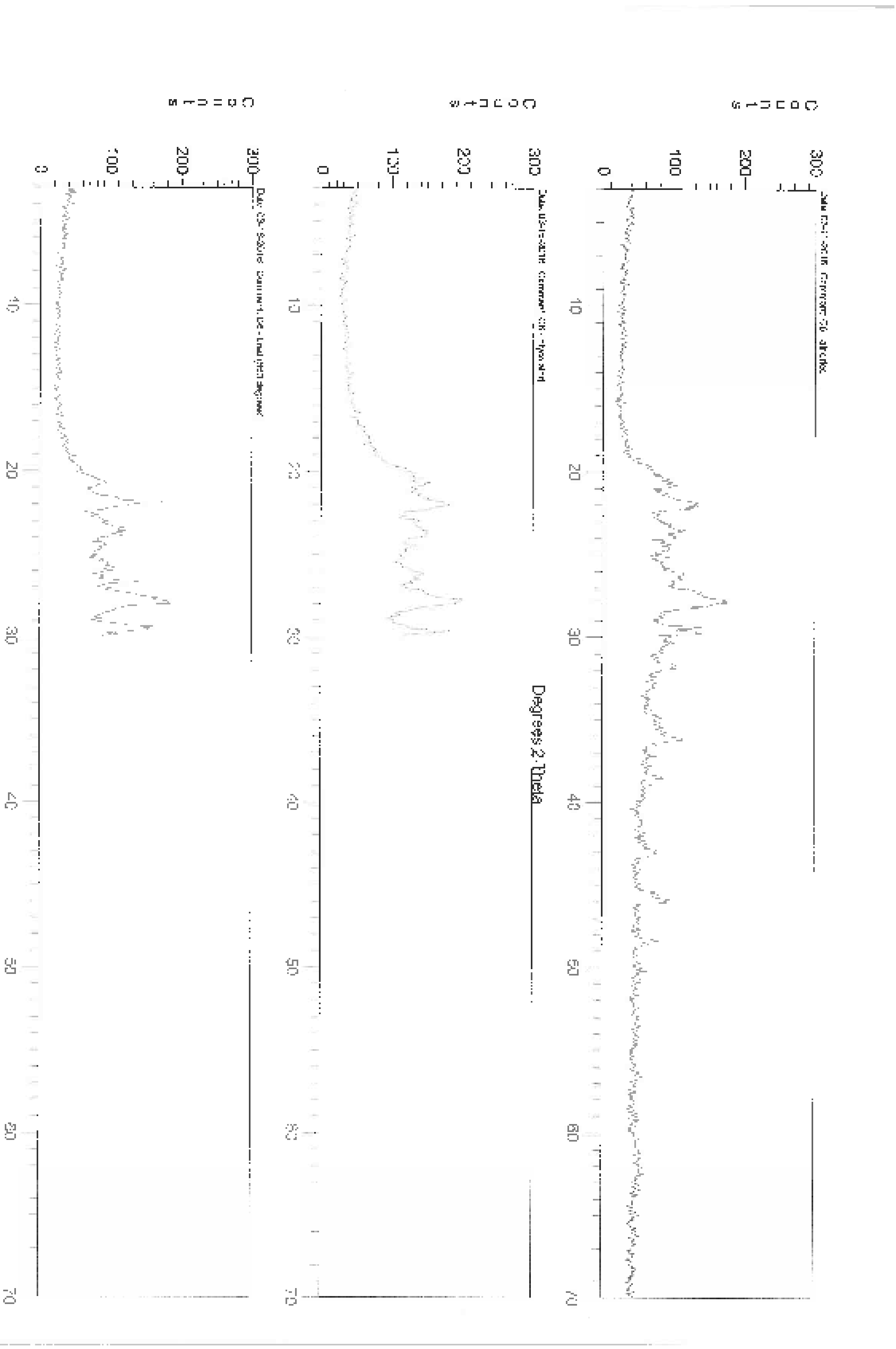
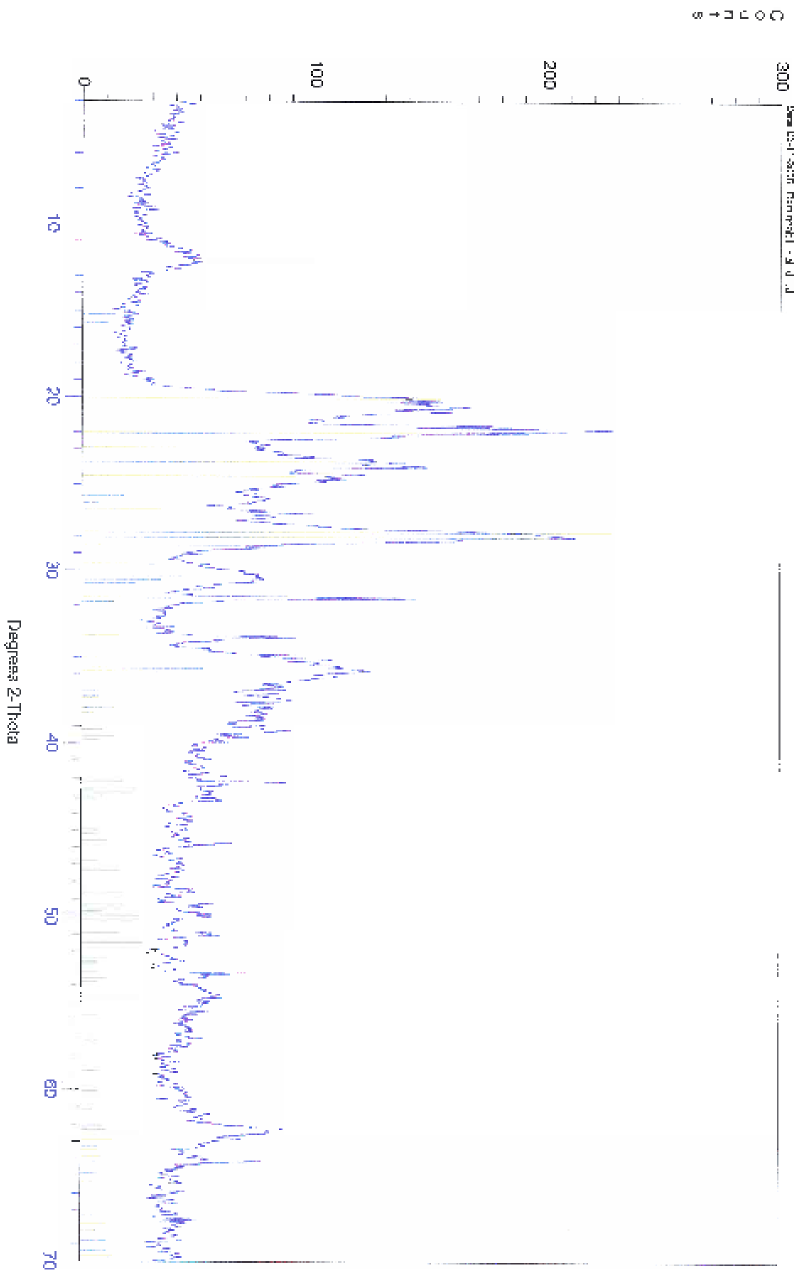
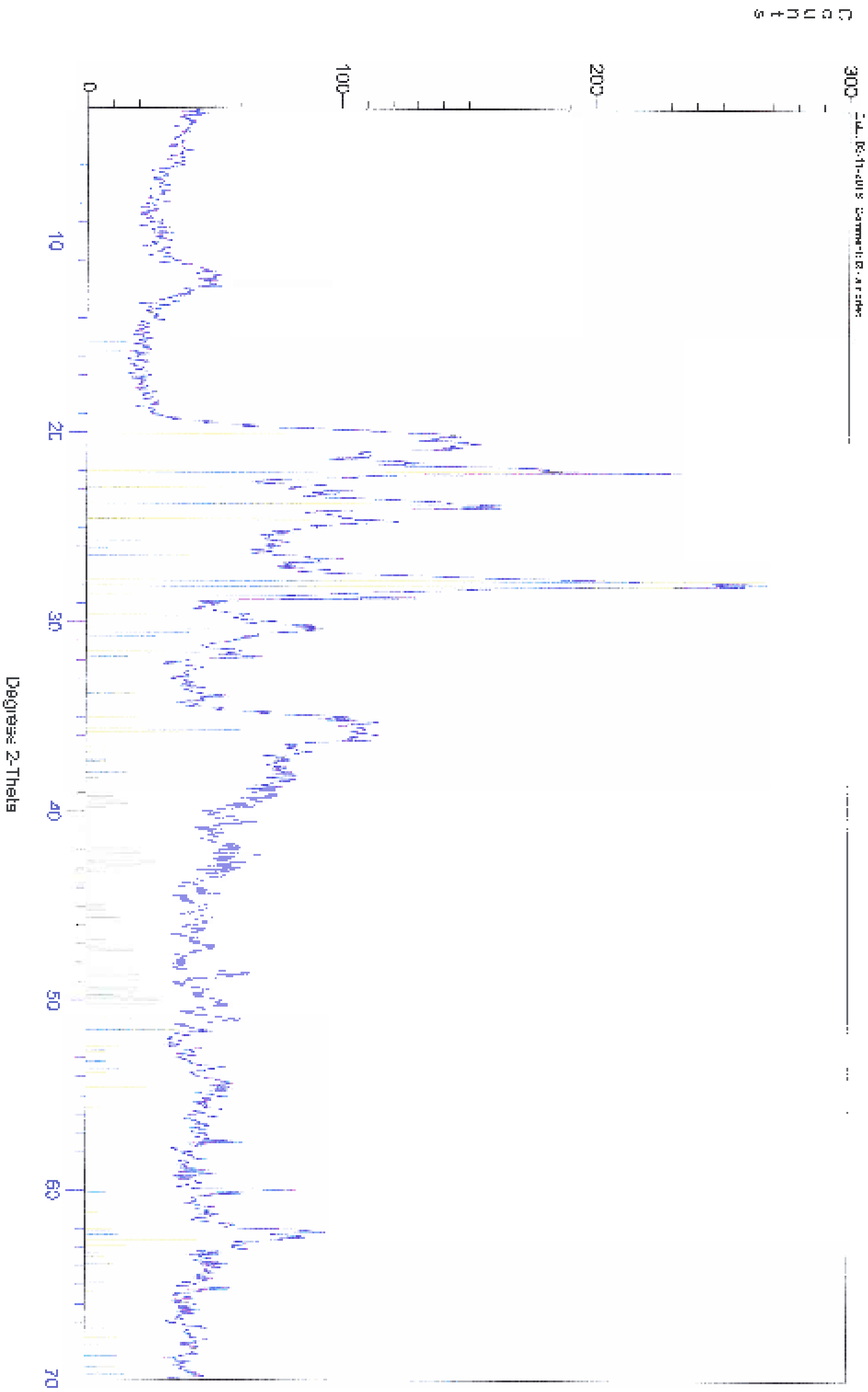
50
60
70
Degrees 2-Theta


Counts
Counts
Counts
Degrees 2-Theta

L.4In-Filling Material XRD Spectrum




Counts
Counts
Counts
Degrees 2-Theta
0
100
200
300
10
20
30
40
50
60
70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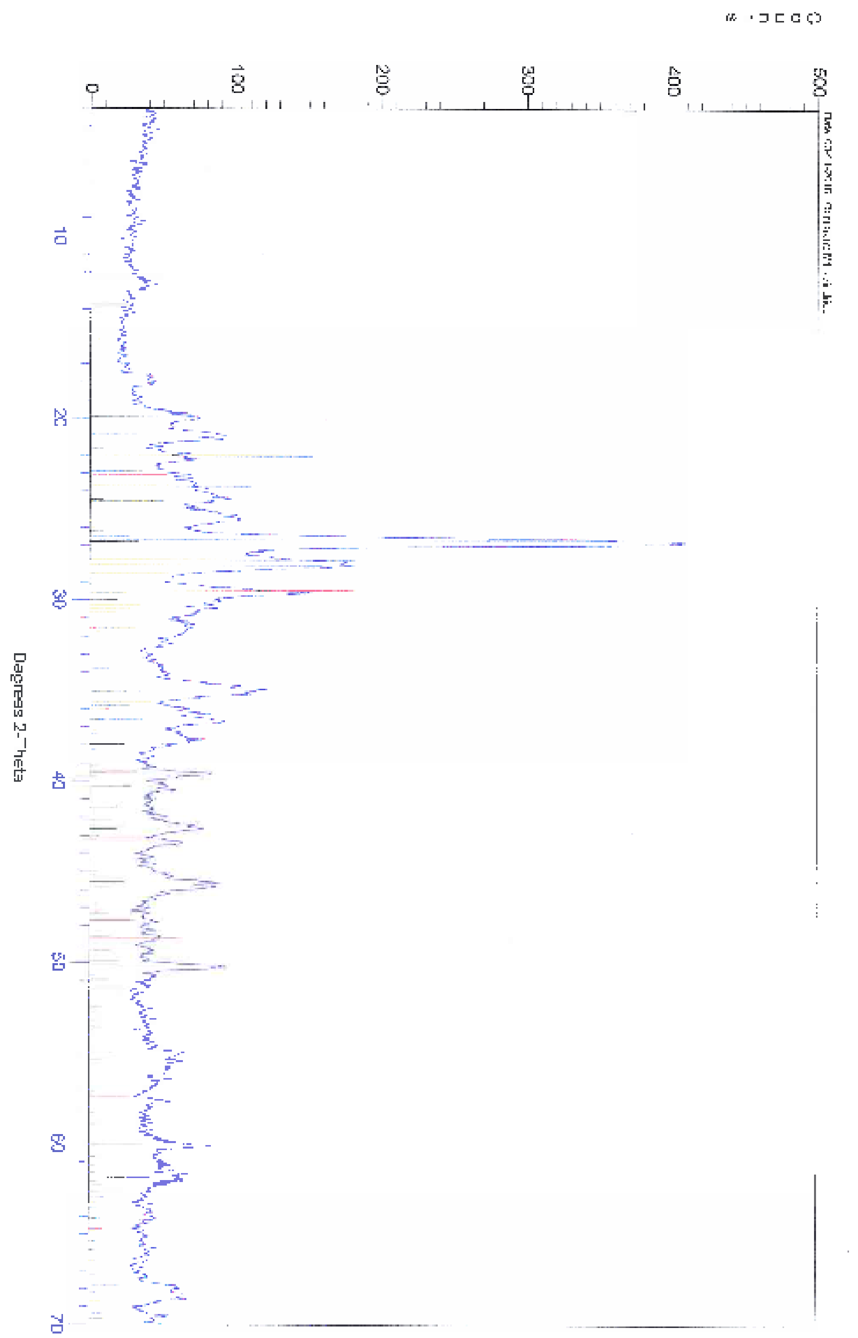
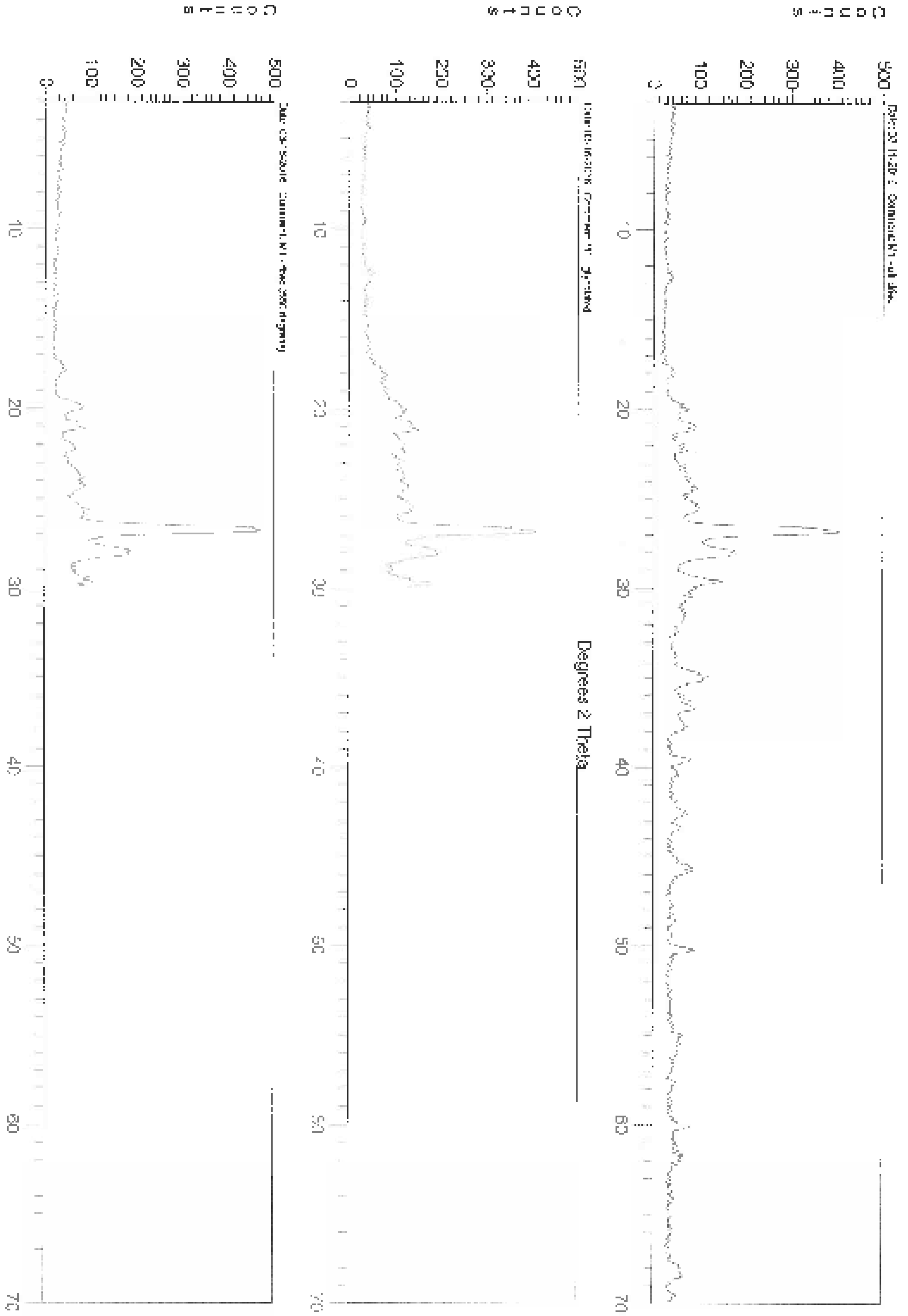
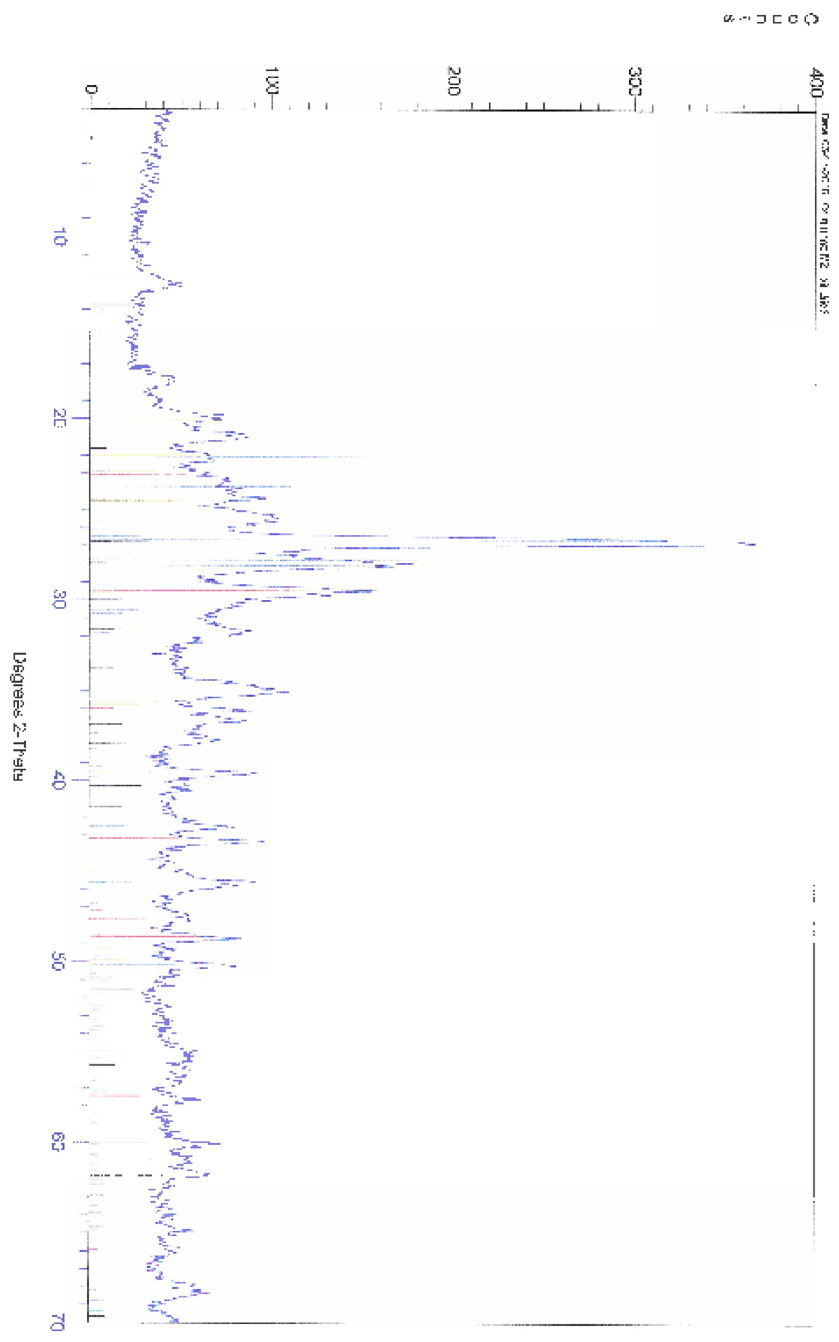
40
50
60
70
Degrees 2-Theta


Counts
Degrees 2-Theta

L.5Control Stone XRD Spectrum




Counts
Counts
Counts
Degrees 2 Theta


Counts
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300
400
10
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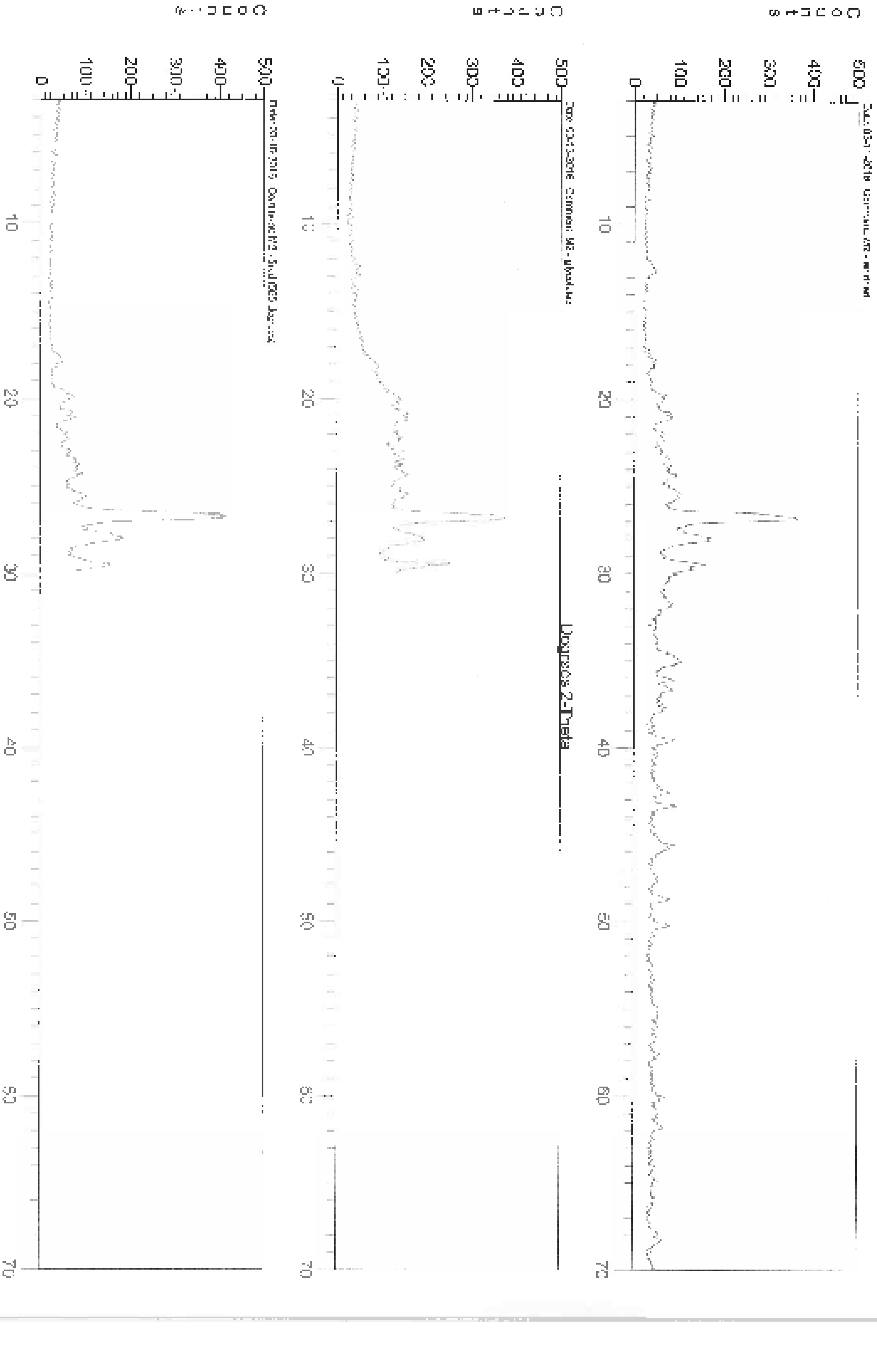
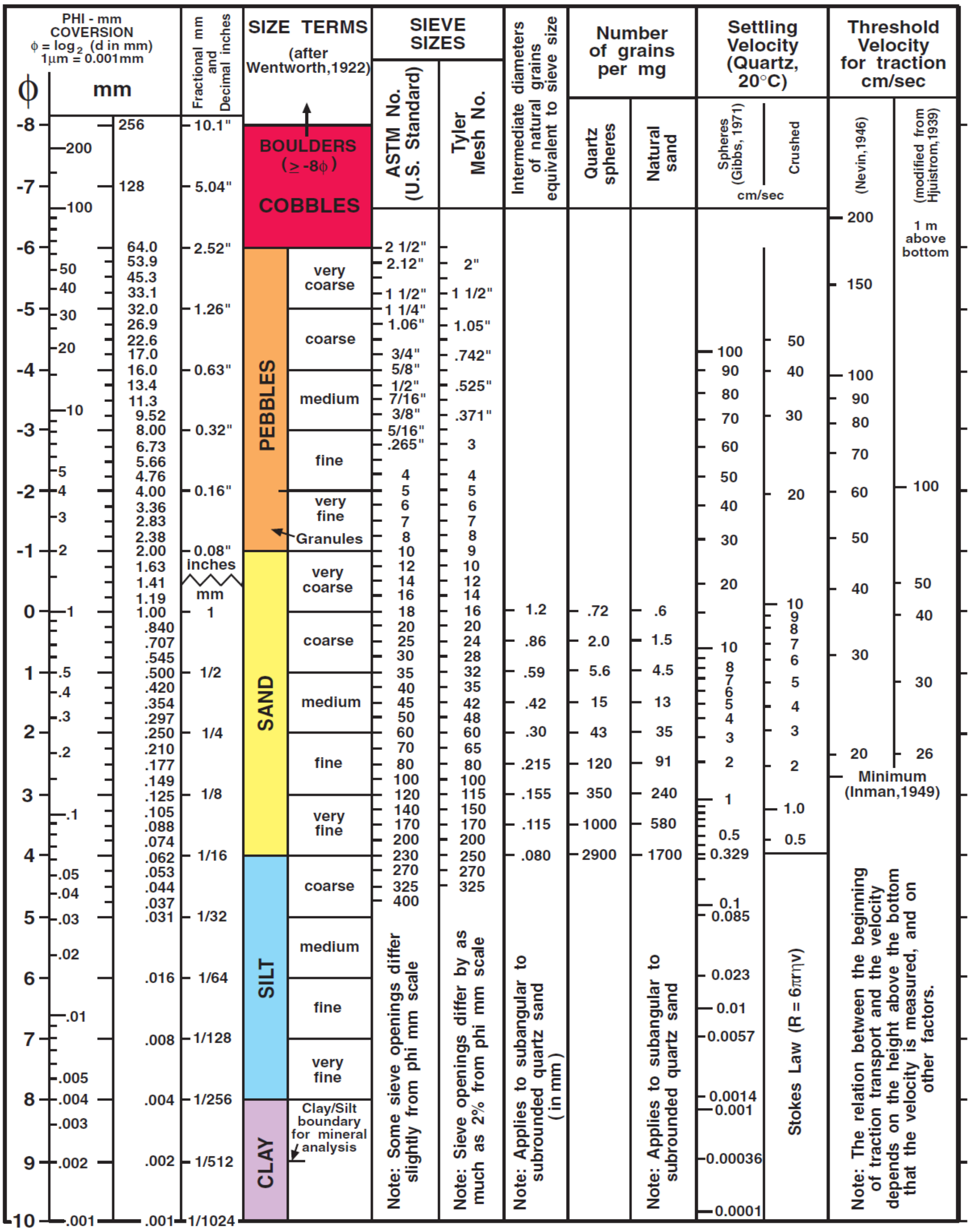
40
50
60
70
Degrees 2-Theta


Counts
Degrees 2-Theta

M. Appendix M: Particle Size Chart

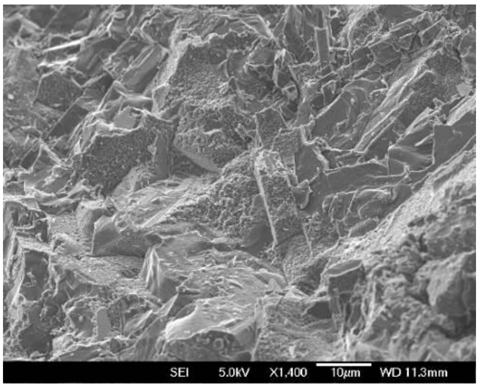
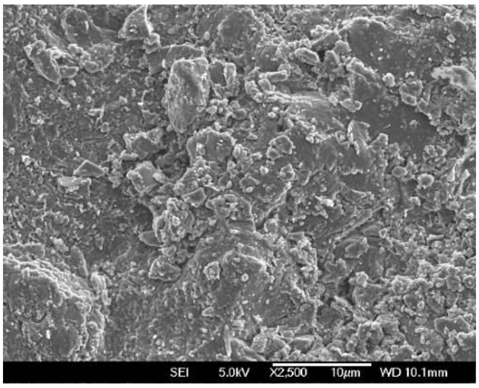


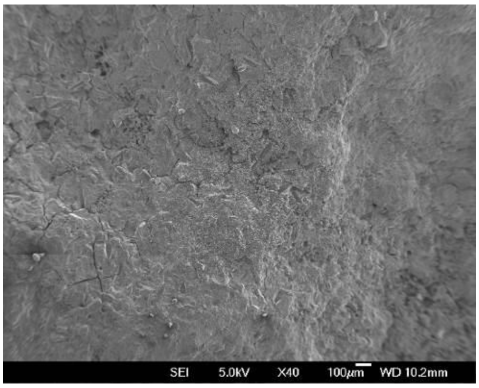
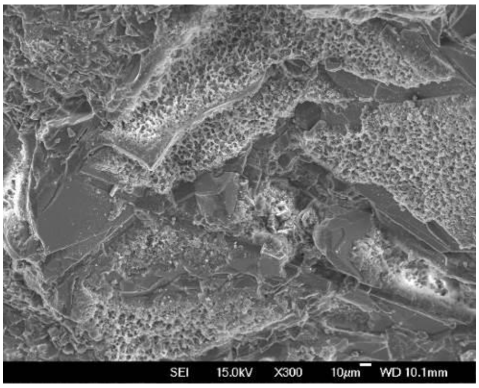
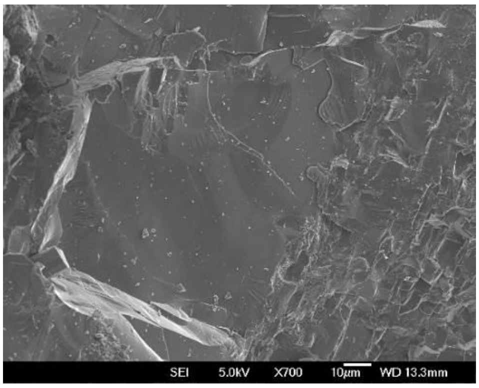
M.1 Reference

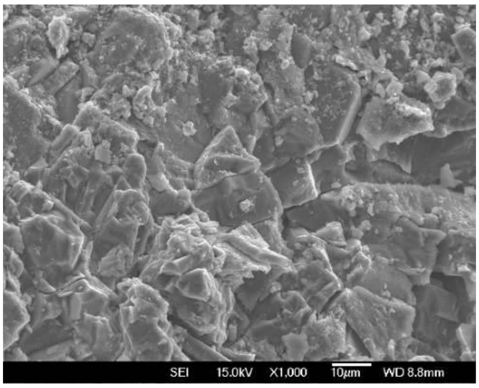
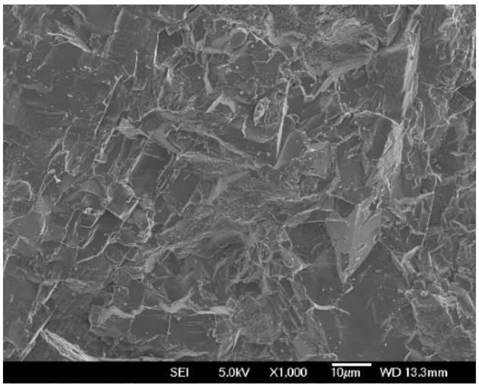
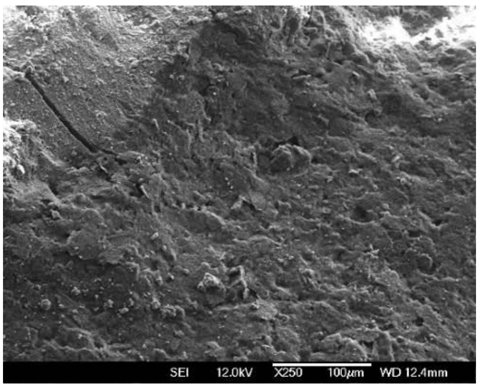
USGS. (2016). U.S. Geological Survey Open-File Report 03-001. *Wentworth Grade Scale*. USGS.

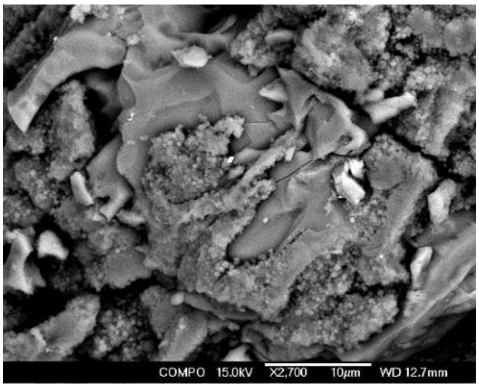
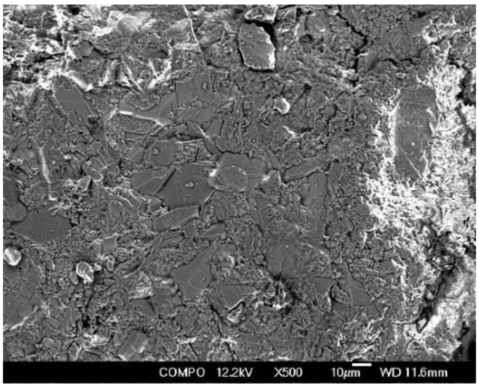
N. Appendix N: Additional SEM analysis

Table N.1 Additional SEM imagery and analysis

Image	Description
1. 	T-Grade rock sample with some alteration, this is visible where the uniformity of the rock mass is decreased and the uneven pitted like texture is visible. Tabular like structures are minerals, some with dissolution texture on the surface. Not all surfaces have undergone a dissolution process. Cooling cracks evident on the surface of some minerals. Fracturing is not common, some fragments look to be shearing off surfaces or they have precipitated out from a solution.
2. 	T-Grade rock with evidence of deposition indicated by spate particles lying on the surface (EG soaked?) Areas of alteration are evident in the left bottom corner of the image with some homogenous material centre right, overlain with what appears to be loose particles. These loose particles are unexplained (and could relate to the EG soaking).

3. 	T-Grade rock piece with a more homogenous rock mass with fracturing evident in random orientations. There is no clear evidence of fracturing around minerals grains as the mineral grains are difficult to identify.
4. 	G-Grade rock showing extensive alteration in bright areas that has a corn flake appearance. Alteration is favoured along cleavage planes as layers are evident
5. 	C-Grade: Massive rock mass with little fracturing and alteration. Brittle fracturing in concentric rings and also running parallel. This is indicative of brittle fracturing like to have occurred after cooling and mineralisation.

6. 	C-Grade rock fragment soaked previously soaked in ethylene glycol. Little alteration is evident but particles are visible on the surface of the rock fragment, either deposited there during processing (soaking or drying) or crystallised from another in-field process.
7. 	C-Grade rock with little alteration or fracturing (compare with Image 6 at the same magnification)
8. 	T-Grade sample prepared to expose a freshly weathered face. A fracture is visible in the top left hand corner which is overgrown with other crystals which indicates the fracture was a pre-historic fracture and not introduced do to production processes.

9. 	C-Grade rock with crystallised minerals in the form of a solution flow (w shape in the centre of the image). This has emplaced over an existing fracture which indicates that the fracture was pre-historic. Areas of uneven surface texture are likely to be mineral crystallisation that occurred from a solution after original emplacement.
10. 	T-Grade sample prepared to expose a freshly weathered face. Fracturing around minerals is evident. Bright white area to the right of the image is likely to be over exposure of the detector and less likely to be alteration.